

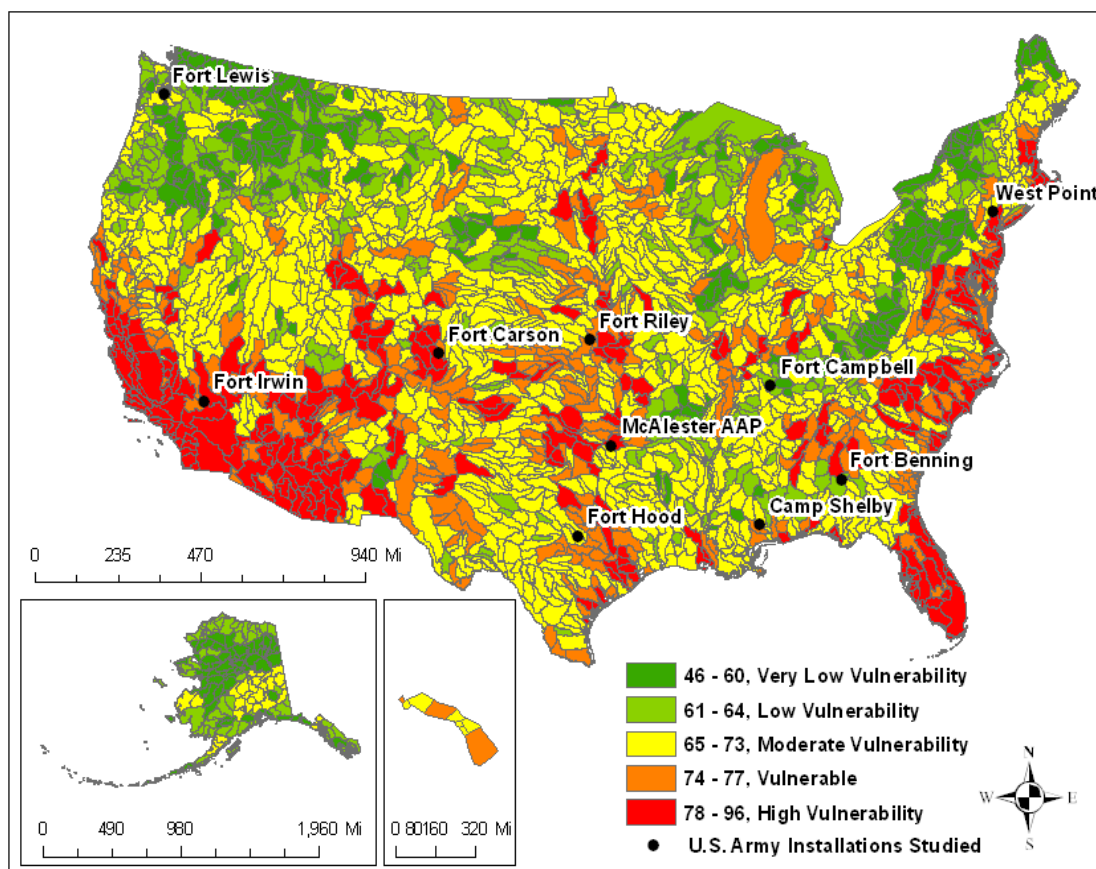


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## Water Sustainability Assessment for Ten Army Installations

Elisabeth M. Jenicek, Rebecca A. Carroll, Laura E. Curvey,  
MeLena S. Hessel, Ryan M. Holmes, and Elizabeth Pearson

March 2011







**US Army Corps  
of Engineers®**  
Engineer Research and  
Development Center



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March 2011

## **Water Sustainability Assessment for Ten Army Installations**

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Final Report

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**Abstract:** A key concern for the US Army is the vulnerability of military installations to critical resource issues. Water issues of concern, including adequate supply, increased cost of production per unit volume, quality, habitat degradation and salinity issues, already impact military installations and military operations in many locations within the nation and across the globe. There is a need to assess vulnerability of regions and installations to water supply and to develop strategies to ameliorate any adverse effects on military sustainment. These analyses —completed on a watershed level and projected over a 30-year time frame— include estimates of both installation and regional water demand. Assessments were completed for ten Army bases across the United States. Results depict a range of installation water sustainability conditions that reflect the larger picture of water sustainability across the United States and around the world. The Army is applying the results of these studies to develop policies that will support sustainable long-term water supplies.

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## Preface

This study was conducted for the Army Environmental Policy Institute (AEPI) under the Project, “Application of Water Assessment Methodology at 10 Installations,” via Military Interdepartmental Purchase Request (MIPR) 9EDBPAEP08. The technical monitor was Dr. Marc Kodack, Senior Fellow, AEPI.

The work was managed and executed by the Energy Branch (CF-E) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL principal investigator was Elisabeth M. Jenicek (CF-E). Part of this work was completed by Rebecca Carroll, Laura Curvey, MeLena Hessel, and Ryan Holmes of UIUC under Contract W9132T-10-C-0010. Special appreciation is owed to the installation and other local points of contact for providing information that was invaluable to this study and for reviewing this report. These individuals are: Vernon Duck, Fort Benning, GA; Ted Reece and Mark Linkous, Fort Campbell, KY; Scott Clark and Vincent Guthrie, Fort Carson, CO; Riki Young and Bobby Lynn, Fort Hood, TX; Christina Spang, Fort Irwin, CA; Joseph Gibbens, Joint Base Lewis-McChord, WA; Walter Gatsche, III, McAlester AAP, OK; Scott Gard, Fort Riley, KS; Michael Reed, Camp Shelby, MS; and James Hoffman, Mississippi Department of Environmental Quality. Franklin H. Holcomb is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Mr. William D. Goran. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the US Army Engineer Research and Development Center (ERDC), US Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Gary E. Johnston, and the Director of ERDC is Dr. Jeffery P. Holland.

## Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
angstroms	0.1	nanometers
atmosphere (standard)	101.325	kilopascals
bars	100	kilopascals
British thermal units (International Table)	1,055.056	joules
centipoises	0.001	pascal seconds
centistokes	1.0 E-06	square meters per second
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
fathoms	1.8288	meters
feet	0.3048	meters
foot-pounds force	1.355818	joules
gallons (US liquid)	3.785412 E-03	cubic meters
hectares	1.0 E+04	square meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
kilotons (nuclear equivalent of TNT)	4.184	terajoules
knots	0.5144444	meters per second
microinches	0.0254	micrometers
microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (US statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
ounces (mass)	0.02834952	kilograms
ounces (US fluid)	2.957353 E-05	cubic meters

Multiply	By	To Obtain
pints (US liquid)	4.73176 E-04	cubic meters
pints (US liquid)	0.473176	liters
pounds (force)	4.448222	newtons
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
quarts (US liquid)	9.463529 E-04	cubic meters
slugs	14.59390	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (force)	8,896.443	newtons
tons (force) per square foot	95.76052	kilopascals
tons (long) per cubic yard	1,328.939	kilograms per cubic meter
tons (nuclear equivalent of TNT)	4.184 E+09	joules
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters



# 1 Introduction

## Background

A key concern for the US Army is the vulnerability of military installations to critical resource issues. In recent years, military installations have been impacted by conditions of increasing demand and decreasing supply of high quality fresh water. Urban growth adjacent to installations has combined with prolonged regional droughts to place key military missions at risk due to limited availability of this vital resource. Regional competition for water threatens continued availability of adequate water both on post and in adjacent urban areas.

The US Army recognizes the emergence of water scarcity as an issue of concern and includes water efficiency statements and goals in sustainability directives. The Army Sustainable Design and Development Policy contains provisions for water conservation as does the Army Sustainability Campaign plan. In the utilities arena, water policy can most often be found with energy. National policy, such as EISA 2007, E.O. 13423, and E.O. 13514 are captured in documents such as the Department of Defense Strategic Sustainability Performance Plan (1Aug2010) and the Army's Installation Management Campaign Plan (5Mar2010).

The study documented in this report is one in a series supported by the Army Environmental Policy Institute (AEPI). Previous reports developed methodologies for conducting national watershed screenings, creating regional water budgets, and projecting installation water demand based on alternate future scenarios. The purpose of these studies is to inform Army leadership about issues affecting installation water sustainability and to affect changes in Army policy.

Army installations are widespread, located in a wide range of geographies and climate regimes. Globally, enduring installations are located in the United States, Germany, Italy, Korea, and Japan. Additionally, Forward Operating Bases and Sites can be found in Romania, Bulgaria, Iraq, Afghanistan, and the African continent.

This study examines water sustainability at ten enduring Army installations in the United States. Many of the posts have experienced or are experiencing the challenges that accompany transformation initiatives. In addition, each is subject to a unique set of regional stressors that affect water sustainability.

## Objectives

The objective of this study was to provide an assessment of regional water scarcity as it affects Army installations in some domestic locations to ensure continued viability and sustainability of Army operations. Results of the assessment are being used to formulate strategies for achieving water efficiency goals and to present recommendations for changes to Army policy to plan for a secure water future.

## Approach

Installation water scarcity was assessed by applying methods for conducting a regional water balance or budget. Regional water budgets identify sources of water supply and demand for the water resources used by Army installations. The product is an input-output model of regional water supply and demand. Model variables were altered to produce alternate future scenarios used to evaluate the potential impact on availability of water for these Army installations.

The Installation Water Demand Model was used to develop water use estimates projecting 30 years into the future. The model uses installation-specific data about historic water use and existing and planned building stock to project future demand. Regional water demand is calculated using historic regional water data, existing and planned water conservation measures, and projected population changes.

Both the regional water balance method and the Installation Water Demand Model are documented in ERDC/CERL TR-09-38, *Army Installations Water Sustainability Assessment: An Evaluation of Vulnerability to Water Supply*.\*

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\* Accessible through URL: <http://libweb.wes.army.mil/uhtbin/hyperion/CERL-TR-09-38.pdf>



## **Mode of technology transfer**

This research will be presented at workshops and symposia, and this report will be made available through the World Wide Web (WWW) at the following public URL: <http://www.cecer.Army.mil>

## **2 Army Water Vulnerability**

### **National water trends**

The amount of fresh water globally is finite while human demand for this life-sustaining resource continues to grow. The human pressures affecting water resources are most often related to factors such as demographics, economic trends, legal decisions, and climatic fluctuations. The US population has doubled since 1950. This resulted in increased direct human demand and also influenced water requirements to meet increased food and energy production (Figure 1). Degradation of existing freshwater supplies is another factor that limits water security.

#### **Water demand**

Estimated water use in the United States for 2005 was 410 billion gallons per day (Bgal/d). This is slightly less than the estimate for 2000. Total water withdrawals decreased by 1 percent between 2000 and 2005, while the population increased by 5 percent and continued the 50-year trend of population shift from rural to urban areas. The greatest increases in water use since 1950, when the U. S. Geological Survey began its series of water-use compilations, were experienced in Southern and Western states with commensurate increases in water demand following. Water use in the United States peaked in 1980 due primarily to progressively greater amounts of water withdrawn for irrigation and thermoelectric power generation. The number of irrigated acres increased from 1950 to 2000 while withdrawals remained constant or decreased. USGS attributes this decline to substitution of sprinklers for flood systems and a corresponding decrease in conveyance losses (Kenny et al. 2009).

Water withdrawals for public supply increased only 2 percent between 2000 and 2005 while population increased by more than 5 percent. Per capita use, combining both domestic self-supplied and public-supplied deliveries, was 98 gallons per capita per day (gpd); 1995 use was 101 gpd. Usage varies widely between states, ranging from a high of 190 gpd in Nevada to a low of 54 gpd in Maine. The states with the highest domestic usage are California, Texas, New York, Florida, and Illinois. The largest self-supplied withdrawals are in California, Texas, and Michigan.

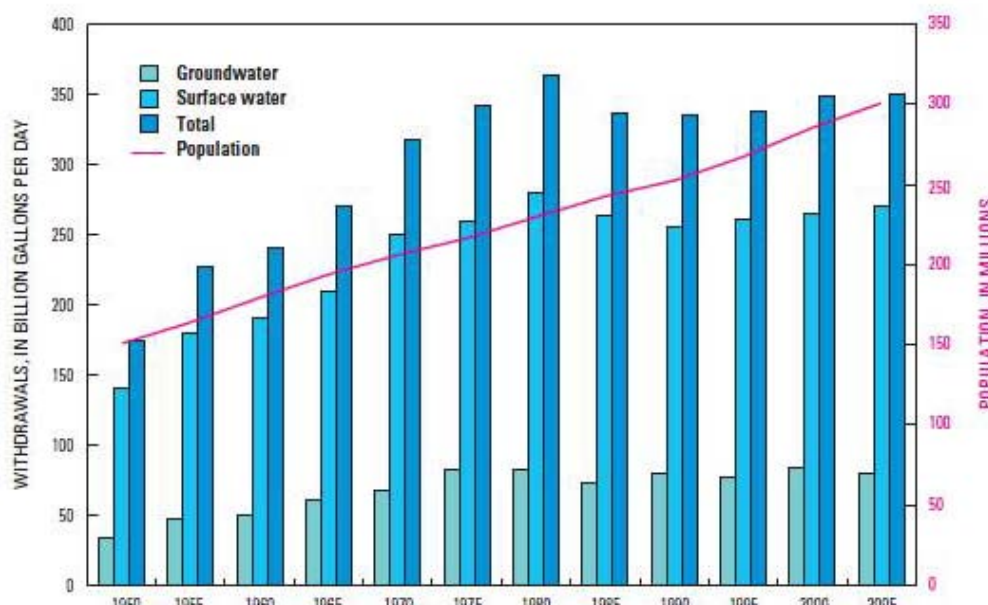


Figure 1. Trends in population and freshwater withdrawals by source, 1950-2005 (Kenney et al. 2009).

### Groundwater depletion

Groundwater meets drinking water needs for about half of the total population and all of the rural population. In addition, it provides 50 Bgal/d for agricultural needs. Groundwater depletion is the long-term decline caused by sustained groundwater pumping and is an issue of concern in many areas of the United States. Negative impacts of groundwater depletion include lowering of the water table, increased pumping costs, reduction of water in streams and lakes, land subsidence, and deterioration of water quality due to saltwater intrusion.

Groundwater depletion is an issue of concern in the Southwest and High Plains though increasing demand has overstressed aquifers in many areas of the United States. Groundwater depletion can occur at scales from a single well to an entire aquifer system. Adverse impacts in the Atlantic Coastal Plain include reduced base flow of streams and saline movement inland. In West Central Florida groundwater development caused saltwater intrusion and sinkholes. Groundwater decline and subsidence are the impacts along the Gulf Coastal Plain. Water level declines have also been noted in the High Plains, Pacific Northwest, and Desert Southwest (Figure 2). Long-term pumping of groundwater in the Chicago-Milwaukee area lowered levels by as much as 900 feet (Reilly et al. 2008).

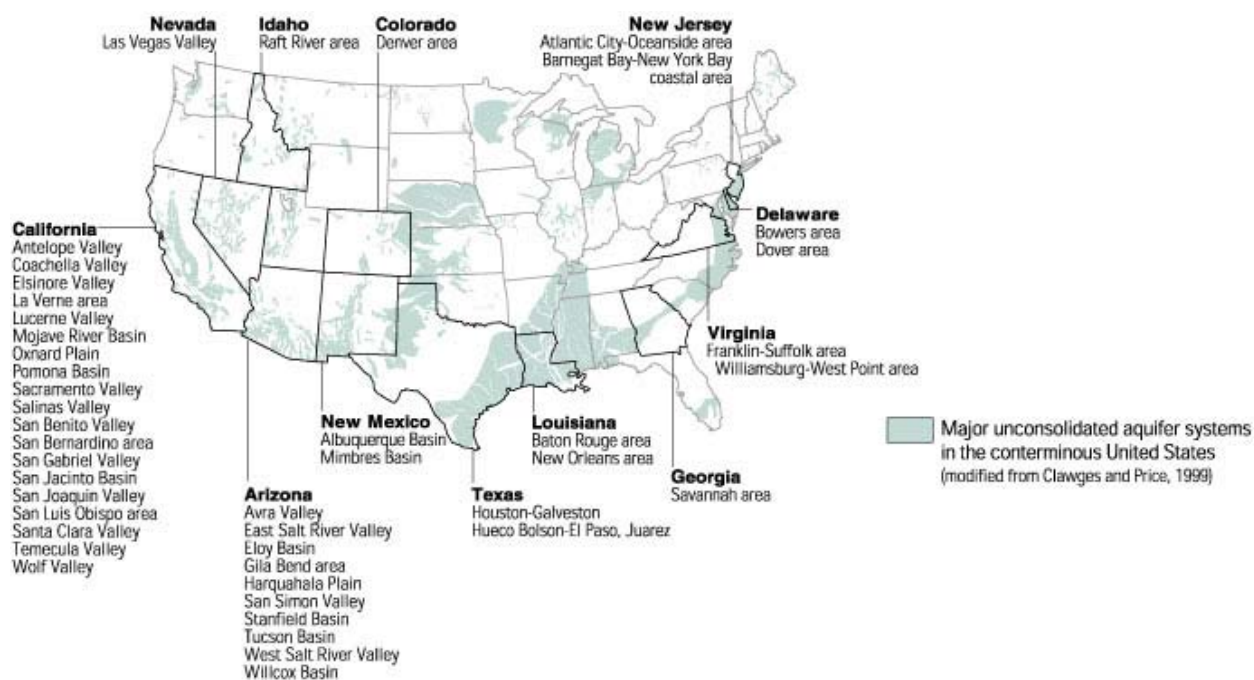


Figure 2. Areas where subsidence is attributed to groundwater pumpage (Galloway et al. 1999)

## Climate change

Water availability is also subject to the impacts of global climate change. Climate change is projected to have a variety of effects on water including supply reliability, flood risk, health, agriculture, energy and aquatic systems. The main climate drivers that affect water are changing temperature and precipitation and rising global sea levels (Brekke et al. 2009). Specifically, increasing global temperature has the immediate effect of producing higher evaporation rates, thereby drying soils, increasing irrigation requirements of agriculture, and reducing reservoirs of surface water. Aquifer recharge will also fall, accelerating groundwater depletion. A range of changes to weather patterns are anticipated. These include both increased flooding and drought, sometimes within the same region, as storm events become larger and more seasonal. Freshwater supplies are expected to decrease and become vulnerable to salinization. Reduced snowpack and glacier melt is expected to diminish water availability for seasonal demands (McKeown and Gardner 2009). In addition, earlier snowmelt will reduce surface water availability for late-season agricultural needs.

Many of these impacts are already occurring. Nine of the 10 warmest years on record have occurred during the past decade. Temperature data support other observations such as increasing ocean temperatures, shrinking mountain glaciers, and decreasing polar ice cover. Change in the polar regions are already occurring. Plants are flowering earlier and species that rely on sea ice for habitat are declining (National Research Council 2008).

Water supplies in up to 70 percent of counties may be at risk due to climate change. More than 1,100 counties (one-third of counties in the lower 48) are at high or extreme risk of water shortages by mid-century as the result of global warming. That is, demand for water is expected to outstrip supplies at an accelerated climate-driven rate if no action is taken (Roy et al. 2010).

#### **Water law**

Allocation of water in the United States is determined on the state level and is often based on decisions made during times of more plentiful supply and lower demand. An example of how these historical decisions play out in the 21<sup>st</sup> century is the Law of the River, a set of collective agreements that divide the rights to the waters of the Colorado River among seven states. The main provisions were established in 1922 and currently allocate more rights than there is water available from the river. The Colorado serves 30 million people and travels more than 1400 miles from its origin in the Rocky Mountains to the river's mouth at the Upper Gulf of California (Sea of Cortez) (IEEE 2010).

Disputed water is becoming all too common in the United States. Over 95 percent of available freshwater resources in the United States cross state boundaries and are affected by compacts. Although there are 39 inter-state freshwater compacts in the United States, some areas, such as a part of the Mississippi River Basin, do not have compacts in place (Hall 2010). Many existing compacts base water allocation on an overly optimistic forecast of water availability, particularly given regional warming trends.

#### **Energy and water**

Approximately 40 percent of water use in the United States is used for energy. This is largely as cooling water for power generation plants. The

total consumptive use is 3 percent.\* Trends away from once-through cooling and toward recirculating cooling reduced the ratio of total water withdrawals to energy produced (gallons per kilowatt hour) from 63 gal/kWh during 1950 to 23 gal/kWh during 2005 (Kenney et al. 2009).

Renewable energy is one solution to increasing energy demand accompanied by concerns over imported oil and the climate impacts of burning fossil fuel. Solving one resource problem can cause another if all implications are not considered. Alterations in water temperature, quality, volume or seasonally available flow, and other factors are important to both human and ecological needs. Examples of collisions between renewable energy and water are not difficult to find. Exploiting a fault line beneath the Salton Sea in California to produce 2300 megawatts of power requires pumping water from the Colorado River. Production of biofuels from irrigated crops can consume 12 gallons of water per mile driven; this compares to 0.14 gallons of water required per mile driven using gasoline or diesel.

The Army's renewable energy goal is to achieve 5 percent of total electric use from renewable sources by 2010, one that is unlikely to be met, while the Department of Defense seeks 25 percent renewable by 2025 (Smith et al. 2010). Other pressures can be felt from state targets. California has set the ambitious goal of generating 33 percent of its electricity from renewable sources by 2020. One project on the books that would help meet that goal is the planned-for 500 MW mixed solar thermal and solar photovoltaic power station at Fort Irwin. Some renewable energy options require little, if any water. However, the water requirements should be considered for each renewable energy development.

Lack of water can also affect energy production. Hoover Dam's 17 turbines generating 2080 MW cannot operate at full capacity when the waters of Lake Mead drop. Below 320 meters can damage the turbo generators. Lake Mead has not been full (372 m) in 10 years due to drought conditions that began in 1999 (IEEE 2010). Water quality has been impacted through extraction of natural gas by "fracking," i.e., injecting large quantities of water to break up deep rock formations.

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\* National Water Use Information Program, United States Geologic Survey, 1995, is the last time consumptive use for thermoelectric cooling was reported.

### **Infrastructure condition**

There are 240,000 water main breaks per year in the United States. Estimated water loss from distribution systems is 1.7 trillion gallons per year at a cost of \$2.6 billion per year (USEPA 2007). The American Water Works Association targets 15 percent as a typical figure for unaccounted for water (AWWA 2009). The American Society of Civil Engineer's Infrastructure Report Card gives drinking water a "D-." ASCE further identifies an annual shortfall of at least \$11 billion needed to replace facilities at the end of their useful life and to comply with existing and future water regulations (ASCE 2009).

The USEPA's Gap Analysis\* estimated that if water system investment remains static, the funding shortfall could exceed \$500 billion by 2020, \$271 billion for Clean Water capital costs and \$263 billion for Drinking Water capital costs (USEPA 2002).

Infrastructure condition is important for two reasons. Firstly, the age and condition of water distribution systems on-post is similar to those off-post. The reality of water loss through distribution system leakage was addressed in one form through utility privatization. A second reason is that for installations that purchase water from municipal utilities, the condition of local infrastructure can affect availability of water to the Army.

System water losses also carry a heavy energy burden. Southern California Edison estimates that energy savings in the range of 1,020,125,599 KWh/year are possible by addressing water system leaks. That amounts to about 26% of the 2008 California electricity system power generated by coal power plants (Sturm 2010).

### **Army water challenges**

Army installations are vulnerable to the same issues of water supply and demand that jeopardize the national and indeed the global water supply. Providing the required amount of clean fresh water in the location where it is needed is increasingly difficult. The complexity of water compacts, treaties, and agreements is another challenge for Army installations. In the coming years, the impacts of water scarcity will be more severe and this

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\* "Clean Water and Drinking Water Infrastructure Gap Analysis" (2002).

will be reflected in increasing costs. Increased privatization of water systems will be another stimulus for increases in water cost.

The conditions that exacerbate water availability are the aging condition of water infrastructure, generalized population growth especially in regions containing key Army installations, increased demand for power generation plants, and uncertain but generally agreed upon regional impacts of global climate change.

Another complicating factor is that water is a resource that recognizes no boundaries —installation, municipal, county, region, state, and national— other than its own, that of watershed or sub-surface aquifer. Man intervenes in the natural hydraulic systems through inter-basin transfers, the movement of “virtual water” from one water region to another in products, and the increase in water bottling plants. Planning for water sustainability is a regional issue requiring cooperation among a host of players whose decisions affect long-term scarcity.

### **Rising cost of water**

There is a wide variation in water costs across the country and these are reflected in Army water rates. Army installations are subject to the local market for water prices. Water contracts are supported by the Huntsville Division of the Corps of Engineers, which can negotiate and participate in rate interventions if requested. (This rarely happens.) The large backlog of water system upgrades in the United States is starting to be felt through water rates as projects proceed. Water cost is a lagging indicator. (Water utilities must defend decisions to increase rates to Public Utility Commissions.) It can take years to implement water conservation projects once rates become high enough to justify the investment.

Although there is not generally a link between the scarcity of water and its cost, water prices are beginning to rise. This is fueled at least in part by the need for infrastructure investments throughout much of the United States. With water consumption on the decline, system improvements are being largely funded by raising rates for existing customers. Water use has been on the decline for several reasons: loss of industry, decrease in new home construction, migration, and weather (both droughts, which spur conservation; and rains, which reduce the need to irrigate).



The American Water Works Association (AWWA) documents a 12.4 percent increase in cost from 2006 to 2008, or 4.8 percent annually. This compares to the consumer price index (CPI) rate of 4.2 percent annually. Of the utilities surveyed, 9 percent decreased their rates, 7 percent maintained their rates, and 84 percent increased their rates between 2006 and 2008. AWWA's average rate was \$3.05 per thousand gallons based on the survey of 126 water utilities (AWWA 2009).

### **Metering program**

The Energy Policy Act of 2005 requires building level water meters in all covered facilities by 2016. These facilities are defined based on size and/or water use. The meters are automated and will be connected to a central system for remote reading. Presently, it is typical that an installation only meter water at the point of delivery. Reimbursable customers will sometimes have utility meters although their use is often estimated.\* At least one study installation discovered that they were under billing reimbursable customers by half once they installed water meters.

The water use efficiency standards found in the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) 189.1-2009 are mandated in the update to Sustainable Design and Development Policy (Environmental and Energy Performance) (Department of the Army 2010). This update includes requirements for installation of water meters and sub-meters in buildings and systems.

### **Utilities privatization**

On 10 November 1997, the Secretary of Defense, Mr. William S. Cohen, issued a directive to all Military Commanders that utility systems (electric, gas, water and wastewater, and thermal) would be transferred to the private sector. One benefit sought through privatization was modernizing and recapitalizing aging utility systems and bringing them up to current industry standards. Of 355 CONUS utility systems, 146 have been privatized (32 water).† Privatized systems are owned by the contractor who is responsible

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\* From AR 420-41, Acquisition and Sale of Utilities Services: The purchaser will pay to install a meter at a new or existing point of delivery when the utilities sales officer determines that a meter is required. Army and Air Force Exchange Service and other NAF activities that pay for service will be metered, if practical, when the annual use is estimated to be more than \$360.

† 2010 Army Posture Statement, Utilities Privatization.

to provide the utility service including operation, maintenance, and system upgrades. Complications arise when DPW staff desire system modifications in the interest of water conservation. The installation remains responsible for attaining water conservation targets though they may control only a part of the system.

## National screening

Installations were selected for this study to achieve diversity of hydrologic conditions, primary military mission, and Army Major Command (MACOM). An initial list of 20 installations was developed. Additional data were collected and analyzed to reduce this list to ten final study installations.

Hydrologic data were obtained from the watershed application of the Sustainable Installations Regional Resource Assessment (SIRRA) analysis tool. SIRRA contains 17 indicators related to water supply and ten indicators related to water demand. The indicators represent a broad spectrum of issues related to resource availability and development. SIRRA also calculates a rating for vulnerability to issues of water demand, vulnerability to issues of water supply, and overall watershed health. All SIRRA indicators relate to the HUC8\* watershed and that score is then applied to any Army installation lying within the watershed. Complete documentation for SIRRA can be found at <http://datacenter.leadgroup.com/sirra/>.

Regional data used for down-selecting installations include the following: state; main county; metropolitan statistical area; water basin; 2000 population for census designated place; installation's water use as a percentage of the main county; 2008 county population; percent change in county population from 2000 to 2008; projections of county population growth for 2010, 2015, 2020, and 2025; proposed new regional power plants; water stress; projected water stress in 2025; current water scarcity; and, expected future conflicts over water.

Installation data used for down-selecting installations include: SIRRA watershed vulnerability index; expected population increase due to Army

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\* There are 2,280 HUC8 water sheds (Hydrologic Unit Code).

transformation initiatives; MACOM; installation population; installation water use (annual and daily); and, water cost per 1,000 gallons.

A final list of ten installations was recommended. The list was reviewed by MACOM water contacts. As a result, one change was made, substituting McAlester Army Ammunition Plant for Anniston Army Depot. Figure 3 shows the SIRRA map of overall watershed health with an overlay of the ten study installations. Although SIRRA watershed health was just one of the selection criteria, nearly all of the installations are located in watersheds that show some vulnerability to issues of watershed health.

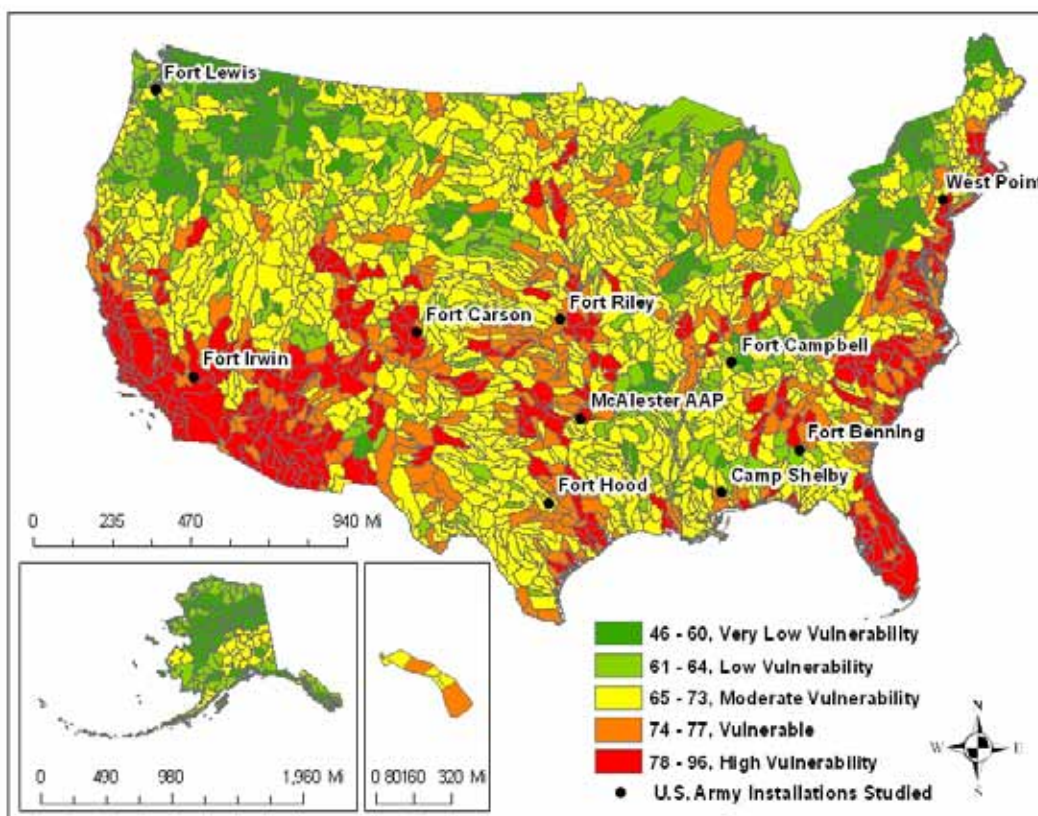
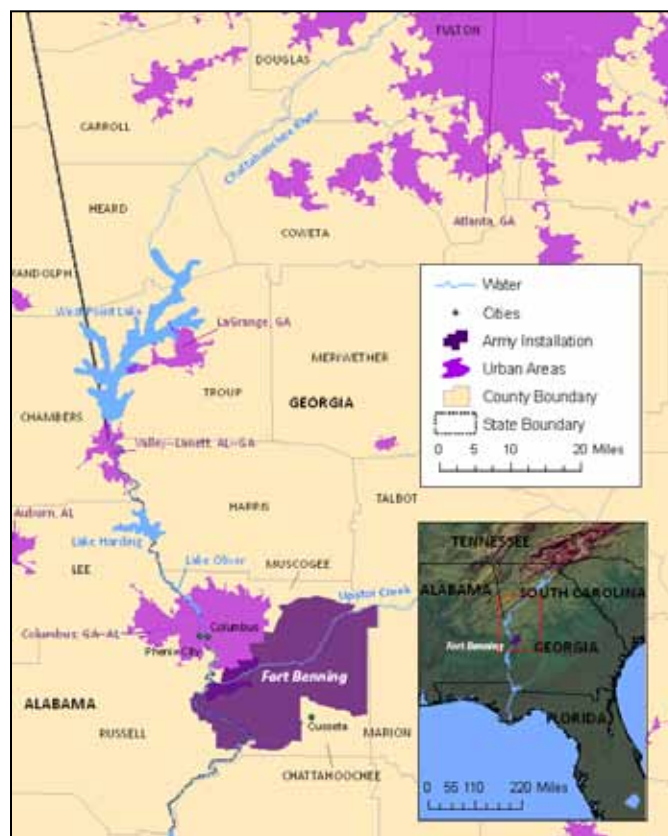


Figure 3. Ten study installations with map of overall watershed health.

### 3 Fort Benning, Georgia, and Alabama

Fort Benning is one of the largest and most populous US Army installations. Fort Benning is located on the Chattahoochee River in western Georgia, immediately downstream from Columbus and almost 120 mi downstream from the greater Atlanta area (TPL 2009). The Fort spans parts of Chattahoochee and Muscogee Counties in Georgia, and a corner of Russell County in eastern Alabama.

Figure 4 shows a map of the installation and surrounding area. Benning serves as a major training center for the US Army. The Fort is home to the newly created Maneuver Center of Excellence — a consolidation of the US Army Infantry School (long located at Fort Benning) and the US Army Armor School (historically housed at Fort Knox). This consolidation is scheduled to be completed by September 2011.



Source: National Atlas

Figure 4. Fort Benning, Georgia and Alabama.

This study analyzes existing data on water availability and usage in the region and projects these trends out to 2040. A series of possible scenarios for water availability in 2040 was developed. These scenarios should help both Fort Benning and the surrounding region plan for adequate water supply in the coming decades.

## Regional characterization of Fort Benning

Both natural and human systems define the Fort Benning region and shape the proposed water scenarios. Fort Benning depends entirely on the Chattahoochee River for its water supply so water supply and demand in neighboring and upstream counties impact the Fort's water availability. Figure 5 shows the regional watershed identified and all the counties potentially considered and finally selected for inclusion in the Fort Benning study region.

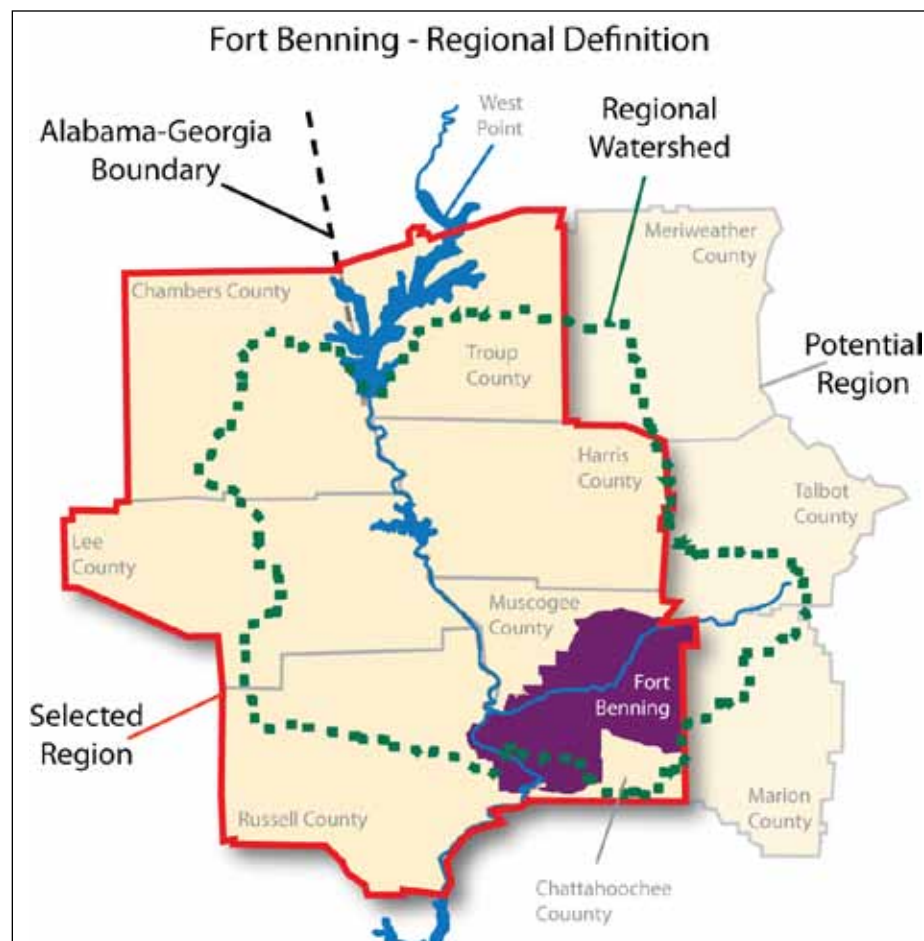


Figure 5. Fort Benning study region.

## Regional definition

Fort Benning sits squarely within the Chattahoochee River Basin. The Chattahoochee flows from its headwaters northeast of Atlanta, down through Georgia, Alabama, and Florida, until it finally empties into the Gulf of Mexico. Fort Benning's current water supply is drawn from Lake Oliver, located just north of Columbus, GA; however, assuming approval of a water withdrawal permit pending at the time of this writing with the Georgia Environmental Protection Division (GAEPD), it will soon be drawn from just downstream of where Upatoi Creek empties into the Chattahoochee (JJG 2009).<sup>\*</sup> Water flow at both these points is determined in large part by how much water is released from West Point Dam into the Chattahoochee River below. Though West Point Dam is not at the headwaters of the Chattahoochee, this degree of control makes it a reasonable start point for the region of study. Additionally, Columbus Water Works, the local utility, uses the controlled flow out of West Point as the basis for ensuring a minimum flow of water through Columbus. Thus, a regional watershed was established, which included all sixth scale hydrologic units (12-digit-HUCs) along the Chattahoochee River basin downstream of West Point Dam and upstream of the hydrologic unit containing the future water intake point for Fort Benning (including that hydrologic unit).

All counties partially within that regional watershed were considered for inclusion in the region of study. For all counties, water supply and water usage were investigated to determine how much water from within the regional watershed was used per county. The region of study included the counties for which estimated water usage from within the watershed was greater than or equal to 1 percent of the total water used within the watershed. Those counties were: Chattahoochee, Harris, Muscogee, and Troup Counties, GA, and Chambers, Lee, and Russell County, AL.<sup>†</sup>

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<sup>\*</sup> Historically, Fort Benning used Upatoi Creek as the main installation water source. However, high levels of silt and turbidity in the creek caused problems that were expected to increase with the addition of the Armor School upstream along the Upatoi. Thus Columbus Water Works (CWW), the local utility, has proposed a new water treatment location immediately downstream of where the Upatoi empties into the Chattahoochee. While waiting for permit approval, Fort Benning has connected to the larger CWW water distribution system, which relies on water from Lake Oliver.

<sup>†</sup> The majority of the data used for the regional determination analysis was obtained from websites of local governing bodies, websites of local utilities, the US Census Bureau, the US Geological Survey (USGS), and the US Environmental Protection Agency (USEPA).

Table 1. Fort Benning regional county populations (2009).

County	2009 Population
Chattahoochee, GA	14,402
Harris, GA	30,138
Muscogee, GA	190,414
Troup, GA	64,653
Chambers, AL	34,320
Lee, AL	135,883
Russell, AL	50,846
Total	520,656
Source: US Census Bureau (2010).	

### Demographic trends

As of 2008, Fort Benning's daily population consisted of roughly 50,000 individuals — members of the military, civilians, trainees, and contractors — who brought with them approximately the same number of dependents. The relocation of the Armor School and Center should add, on average, 30,000 individuals to this mix (Fort Benning 2008). Table 1 lists the estimated 2009 population of each county selected for inclusion in the Fort Benning region. The current total population of the counties chosen is about 520,650, but due to Army transformation initiatives, a new Kia manufacturing plant, and normal growth, this figure is expected to be 678,000 by 2040 — an increase of over 30 percent.

Population projections prepared by the consulting firm Regional Economic Models, Inc. (REMI) were used for all but two of the regional counties. REMI had previously prepared population projections for all counties included in the Fort Benning Regional Growth Management Plan. That study included counties within a 35-mile radius of the main entrance into Fort Benning — the assumed maximum commuting distance (Science Applications International Corporation 2009). This area of study did not include Chambers or Troup Counties so population projections prepared by the state of Alabama were used for the former and by the state of Georgia for the latter. While state population projections were available for all counties, this study has opted to use the REMI-prepared projections because it is assumed that the smaller area of study used in that projection allowed for a greater degree of regional tailoring than state-wide projections. The REMI projections used a cohort-component population projec-

tion model (by sex and race) using net migration with differential treatment of special populations including the military, military dependents, prisoners, and college students (REMI 2007).

The population of the seven-county Fort Benning region is expected to grow from just over 520,650 in 2009 to a population of roughly 678,000 in 2040 — an increase of just over 30 percent. The region is expected to grow much more rapidly during the first few years of that period as the direct and indirect impacts of Army transformation initiatives play out. Roughly a quarter of the region's projected growth between 2009 and 2040 is expected to occur by 2013 — within the first 4 years. This relatively rapid growth means the demand for water will rise steeply — an eventuality for which the area is planning. The accompanying increase of impermeable surfaces in the area will also cause stormwater to reach the river more quickly, and often at a lower quality than was previously the case.

While not within the regional boundaries of this study, the Atlanta-metro area lies along the Chattahoochee, upstream of Fort Benning and the surrounding counties. The Atlanta-metro area has the potential to affect downstream users both directly, through its own use of the water, and indirectly, through ongoing inter-state legal battles over its use of the Chattahoochee's waters (see "Alabama-Florida-Georgia water conflict" [p 20]). The southeastern United States, Georgia, and in particular, the Atlanta metro area have been growing at a rapid pace over the past couple of decades. In fact, between 2000 and 2008, Atlanta moved from the 11<sup>th</sup> to the 8<sup>th</sup> largest metropolitan region in the United States, growing by 27 percent over that time. In contrast, Georgia grew by just 18 percent, and the country at large, by only 8 percent. This rapid growth has had, and will continue to have, important implications for water supply throughout the southeast and in the Fort Benning region.

### **Water sources**

The Chattahoochee River is the major source of water for Fort Benning. It is also the most heavily used river in Georgia — it supplies drinking water for roughly half of Georgia's population in addition to water for agricultural production, recreation, and hydroelectric power generation (Loeffler and Meyer Undated). Likewise, the Chattahoochee is one of the most heavily controlled rivers in Georgia with nine dams and three large impound-



ments providing over 1.6 million acre-feet of conservation storage along its 430-mi journey (Davis and Jordan 2006, USACE 2009).

The origins of the Chattahoochee are in the Blue Ridge Mountains in northeastern Georgia. The river reaches its first major impoundment, Lake Lanier, about 50 mi upstream of the Atlanta area (Davis and Jordan 2006). Lake Lanier provides a significant portion of metro Atlanta's water supply; as of 2000, contracts allowed for a maximum withdrawal of 462 million gallons a day (MGD) from Lake Lanier by neighboring communities (US Army Corps of Engineers, Office of Counsel 2008). The future of Lake Lanier's use as a water supply is unclear, however, due to a July 2009 ruling that the lake, under its current authorization, is not supposed to be used for water supply. This ruling is the latest wrinkle in a decades-long conflict over water use in the various river basins shared by Georgia, Alabama, and Florida (see "Alabama-Florida-Georgia water conflict" [p 20]).

After Lake Lanier, the Chattahoochee passes through the Atlanta-metro area. The river's water quality degrades as it travels through Atlanta and neighboring communities and receives back industrial, agricultural, and municipal wastes and, runoff from storm sewers, suburban lawns, and in some cases, sanitary sewer overflows. Water quality slowly improves as the Chattahoochee continues southwest through more rural areas to West Point Lake at the Georgia-Alabama border, the second major impoundment along the Chattahoochee River (Davis and Jordan 2006).

Thirty miles downstream from West Point Lake, the river flows into Lake Oliver, to the north of Columbus, GA. Lake Oliver is the main source of water for Columbus Water Works — the water utility for both Columbus and Fort Benning. The river is again affected by urban runoff, this time from the Columbus area. Water quality again improves as the Chattahoochee flows through the rural areas south of Fort Benning and toward the Walter F. George Reservoir — the third major impoundment on the river. South of Walter F. George, the Chattahoochee continues along the Georgia-Alabama border toward Florida where it ends at its confluence with the Flint River at Lake Seminole (Davis and Jordan 2006).

### **Alabama-Florida-Georgia water conflict\***

The Chattahoochee river basin is part of a larger watershed — the Apalachicola-Chattahoochee-Flint (ACF) river system — that flows through Georgia, Alabama, and Florida. The three states have historically squabbled over the river system with regard to its use for navigation; water use, however, did not become an issue until the end of the 20<sup>th</sup> century.

Throughout the second half of the twentieth century, the population in and around Atlanta grew very rapidly. As a result of this population growth and the accompanying increased water demand, communities throughout the area requested the use of water in several Army Corps of Engineers reservoirs in northern Georgia. In 1989, after years of study, the Army Corps proposed the reallocation of water from two reservoirs in the ACF watershed, including Lake Lanier, and one reservoir from the neighboring Alabama-Coosa-Tallapoosa (ACT) watershed, which is shared by Georgia and Alabama. This proposal led to concerns in Alabama over the impact of increasing water use in Georgia on water resources in Alabama, and in 1990, the state filed suit challenging the Corps' proposed water reallocation.

At the time, representatives from the three states (Florida was involved because it is part of the ACF basin) agreed that resolving the dispute in court was the least desirable outcome; the suit was stayed and the three states came to the negotiating table. State representatives and experts began working in 1991 to create a shared understanding of water flow through the system so they could develop an allocation formula. The studies and negotiations took millions of dollars and 11 years. In the end, however, the parties were unable to come to an agreement, and in 2003 Florida decided against extending the negotiation period for yet another year — the parties headed back to court.

The legal battle is complex — involving at least eight cases with numerous parties in each lawsuit. In the summer of 2009, however, a major milestone was reached when a Federal judge ruled in a consolidation of seven of those cases that the US Army Corps of Engineers (USACE) post-1970 real-

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\* Unless otherwise noted, information used for this section comes from Davis and Jordan (2006), the Alabama Rivers Alliance (2007), the Atlanta Regional Commission (2008), and the Florida Department of Environmental Protection (2009).

location of water from Lake Lanier to water supply use was illegal and gave USACE and Georgia 4 years to either find an alternate source of water or find a way to legalize this reallocation (i.e., through Congressional action). This decision has been appealed; nevertheless Georgia is under pressure to find a quick solution. Metro Atlanta simply cannot survive on 1970 water allocations.

Georgia is pursuing a variety of options ranging from developing new water sources within the ACF basin to challenging Tennessee regarding which side of the border the Tennessee River falls. However, even if these sources are viable, it is not possible for them to be developed quickly enough to reach the 2013 deadline. Thus, the parties have returned to the negotiating table with renewed hope of finding a compromise. Whatever the ultimate solution may be, its reverberations will be felt throughout the ACF basin.

### **Climate**

This area can be described as having long, hot summers with short, mild winters. Temperatures for the area average around 47 F in January and 82 F in July. The lowest rainfall generally occurs during autumn; overall, area rainfall for the year is typically in excess of 40 in. (Georgia State Climate Office 1998; National Oceanic and Atmospheric Administration 2009).

Drought is a relatively normal component of the climate patterns throughout the southeastern United States. Tree ring records and recorded climate data indicate that Georgia has experienced 14 droughts of 2 years or longer in duration since 1680 (Stooksbury 2003). Alabama, too, has experienced a number of significant droughts, most recently the 2007-2008 drought, which included Alabama's second-driest year on record (2007) (Clark, Spetich, and Evans 2007).

The recent (2007-2008) drought in the southeastern United States was not more severe than earlier regional droughts — however, its water shortages were. This “indicates that the water shortage crisis was largely driven by rising demand,” i.e., population growth (Seager, Tzanova, and Nakamura 2009, p 5042).

As mentioned above, the population of Georgia and the Southeast at large has grown at a rapid pace in recent years, which means that water resources are stretched more tightly in dry times. In the future, such times may come more often than recent historical records indicate. From the mid-1950s through the mid-1990s, the period during which much of Georgia's population growth occurred, droughts were relatively short and infrequent; the more recent 1998-2002 and 2007-2008 droughts are much more similar to Georgia's longer-term climate pattern (Stooksbury 2003).

Furthermore, climate change is expected to increase temperatures, cause stronger, but possibly less frequent, storm events, increase evapotranspiration, and increase the occurrence and intensity of drought conditions throughout the southeastern United States. The most recent climate models predict an average temperature increase of between 4.5 and 9 F for the region by 2080; these predicted increases are higher than those from earlier models and may change again in the future. It is less clear how climate change will affect precipitation in the Southeast — some models predict net decreases, some net increases. Overall, however, it seems likely that the Fort Benning region will experience more intense storm events, which can lead to flooding, and an increase in the intensity, frequency, and duration of droughts (US Global Change Research Program 2009, Intergovernmental Panel on Climate Change 2001, 2007).

### **Topography and geology**

Fort Benning is located on the border between the Piedmont and Coastal Plain physiographic provinces of Georgia and Alabama. While the majority of the base actually lies within the Coastal Plain, the Fort Benning region is split relatively evenly between the two. The northern Fort Benning region is in the Piedmont province and is characterized by low, rolling hills and valleys. The region tends to be rocky and the soil itself is clayey. Towards the south of the region, the physiographic characteristics transition into those of the upper Coastal Plain. The Coastal Plain is relatively flat with a variety of soil types. The transition between the two physiographic regions is characterized by sand hills, which are used for training on Fort Benning, and which also provide a unique habitat for a number of endangered species (Golley 2004, Kirkman 2004, Schmidt 2004).

A GIS analysis of soil types in the regional watershed (drainage basin) revealed that just over 60 percent of the soils in the Fort Benning region have moderate infiltration rates. Most of the remaining soil has either high or low infiltration rates. Relatively little soil in the region is classified as having a very low infiltration rate. Though the soils in both provinces are relatively permeable, the bedrock of the piedmont hampers water penetration into deeper strata. These characteristics have implications for groundwater and base flow as well. The Coastal Plain has larger and more plentiful aquifers than the Piedmont where water may be locally available, but is not predictable due to the rocky earth. Similarly, the sand, silt and clay of the Coastal Plain can store more water than the rocky Piedmont soils so the Piedmont provides less base flow during drought conditions than does the Coastal Plain.

#### **Land use**

A GIS analysis of land cover data from the Multi-Resolution Land Characteristics Consortium (MRLC 2009) indicated that, in 2001, three-quarters of the study area was dominated by undeveloped, though not necessarily virgin, land — forest, grassland/scrub, and wetland. Most of the remaining land was split between urban and agricultural lands, which covered 10 percent and 12 percent of area land respectively.

While the above analysis suggests an area dominated by undeveloped lands, undeveloped lands were the only type of land cover in the region to lose acreage between 1992 and 2001 — urban and agricultural lands saw most of the gains. While the net loss of undeveloped land was quite small, such change is likely to continue into the future, yielding an increase in the speed with which runoff reaches a water body due to new construction increasing regional impervious surfaces. These changes to runoff patterns result in a higher likelihood of flooding during storms. Additionally, increases in agricultural land use have the potential to affect water availability to the installation if the new farmland is irrigated.

The land on Fort Benning experienced less change per-acre between 1992 and 2001 than did the rest of the region. Ongoing Army transformation-related construction will cause Fort Benning to see a decrease of undeveloped land and an increase of urban lands over the coming few years, but overall, will remain dominated by undeveloped lands.



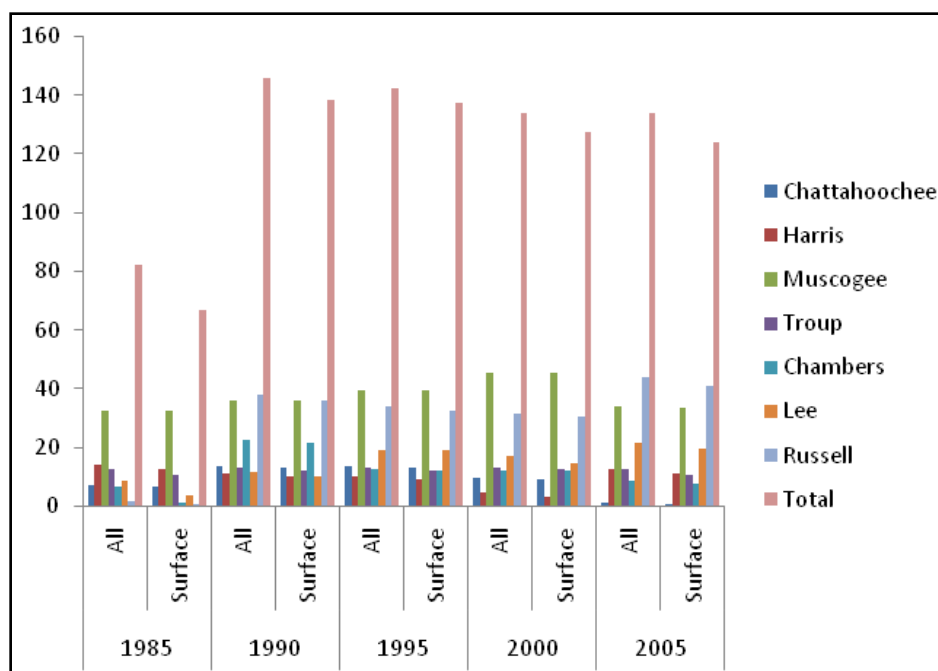


Figure 6. Fort Benning region county level water usage data — 1985-2005.

Finally, some variation in water withdrawals between 2000 and 2005 may be due to the fact that 2005 was a relatively wet year while 2000 was a very dry year. Although there appears to be a spike in total regional water use between 1985 and 1990, overall regional water has been steady, with a trend to slightly declining by 2005.

Between 2007 and 2009, Fort Benning itself used on average 4.8 MGD, all of it from the Chattahoochee river basin. Water usage tends to be higher between June and October, due to higher seasonal water needs, and lowest during January. Since CWW has taken over the Fort Benning water distribution system significant maintenance has been performed resulting in an overall decline in average water usage of 0.59 MGD in 2008 and 2009 (compared to the 2007 baseline). This translates to a water use intensity reduction of 12.3 percent, which indicates that Benning is moving towards meeting the requirements of Executive Order 13514 (personal communication Vernon Duck, Fort Benning Energy Manager 2010), that reducing potable water consumption intensity by 2 percent annually through fiscal year 2020 (FY20), and for a total of 26 percent by the end of FY20, relative to a baseline of the installation's water consumption in fiscal year 2007.

Water withdrawals from the Chattahoochee River are permitted by the Georgia Environmental Protection Division (GAEPD). The user is required to seek a permit from the GAEPD for any water use greater than 100,000 gallons per day on a monthly average (GAEPD 2009). It is unclear how or whether the ongoing negotiations over water use from Lake Lanier will affect water used downstream. Currently, water withdrawals by CWW are limited because the amount of water it is allowed to discharge back into the Chattahoochee River from its waste treatment plants is restricted. CWW has a long pending application for an increase in water discharge into the Chattahoochee, held up by the tri-state litigation, but until (and if) that application is granted, it is limited in the amount of water that it can take from and, in turn, how much water it can return to the river.

## **Developing the Fort Benning regional model**

As previously described, Fort Benning obtains the vast majority of its water from the Chattahoochee River basin. Groundwater is locally available and the installation does operate a few wells, but the current levels of groundwater production are not nearly high enough to match Fort Benning's demand. Fort Benning's water system is privatized, operated by CWW, the main water supplier for the Columbus area. CWW provides the installation with water taken from its main plant, which draws water from Lake Oliver, just north of Columbus. A new water treatment plant is being built on Fort Benning, which will draw water from just south of the confluence of Upatoi Creek, which runs through Fort Benning, with the Chattahoochee River.

### **Water supply model**

This study focuses on the long-term water supply —out to 2040— provided by the Chattahoochee River. Data from 2000 to 2009 are used to create a baseline representing a “typical” water year. The water supply region, as explained above, starts at the mouth of West Point dam and extends south along the river to the hydrologic unit containing the proposed future Fort Benning water supply intake.

Water availability from most surface water sources in Georgia is legally limited by the state's 2001 Interim Instream Flow Protection Strategy, which for an instream withdrawal, such as the one proposed for Benning, allows the applicant to withdraw either: (1) the lesser of the monthly 7Q10



or the inflow to that point,\* (2) a minimum determined by a site-specific study, or (3) 30 percent of the mean annual average flow. However, this policy does not apply to heavily regulated streams such as the Chattahoochee, for which the state is committed to finding a consensus approach for flow protection (Board of Natural Resources 2001).

Although it is unclear from the interim policy precisely what policy should be applied to the Chattahoochee and other heavily regulated streams, it is presumed that the state's older instream flow policy still applies to those streams. This policy states that in the absence of other flow limits as established by the Georgia Department of Natural Resources (DNR), surface water users must allow the annual 7Q10 flow to pass downstream so long as such a flow would not unreasonably adversely affect the stream or other users (Board of Natural Resources 2001). The 7Q10 flow is the lowest 7-day average flow with a recurrence interval of 10 years. In theory, the 7Q10 flow of the Chattahoochee River at the intake point for Fort Benning's water supply represents the legal limit for the installation's water withdrawal.

This older policy was updated precisely because of doubts about its ability to adequately protect minimum river flows. As the interim flow policy states: "[the] DNR's 7Q10 rule ... is NOT based on the science of how much water should remain in a stream to maintain a healthy aquatic community," [emphasis original] (Board of Natural Resources 2001, p 26). Thus, while this water assessment will consider potential scarcity to occur only in situations where water demand is significantly greater than water availability under the older 7Q10 instream flow policy, it will also examine the implications of a more stringent hypothetical policy based on the 2001 Interim Instream Flow Protection Strategy.

#### *Water supply region*

Figure 7 shows a conceptual model of Fort Benning's water supply region. The region begins at West Point Dam, the outlet point for the reservoir at West Point Lake, which is managed by the Army Corps of Engineers. Water flows downstream from West Point Dam, past a number of communities, to the proposed intake point for Fort Benning's water supply just downstream of the mouth of Upatoi Creek.

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\* The "7Q10" flow is a 7-day consecutive low flow which recurs at a frequency of once every 10 years.

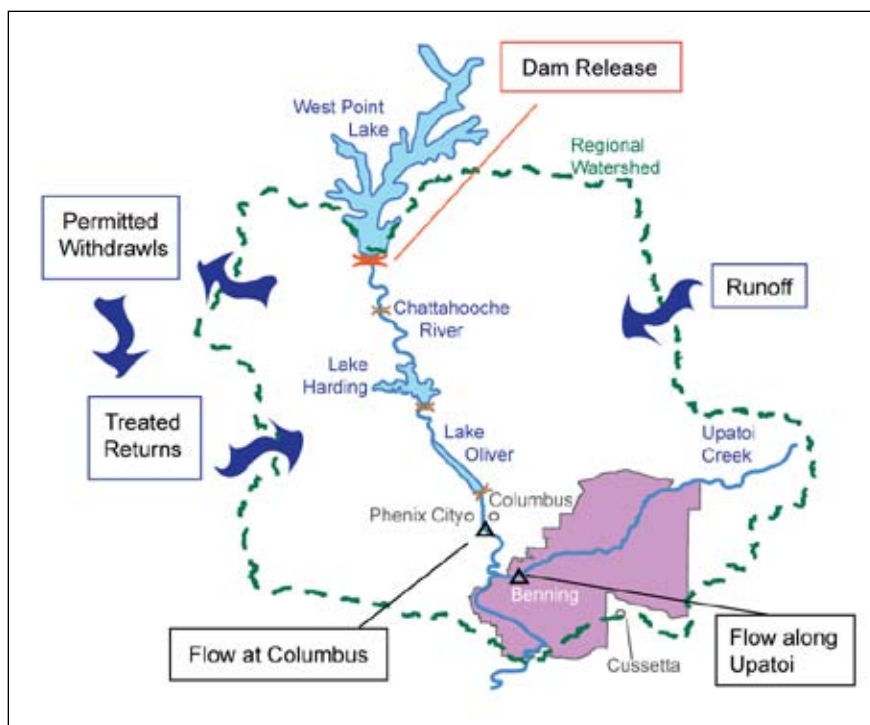


Figure 7. Conceptual model — Fort Benning water supply.

There are a number of additional hydroelectric dams operated by Georgia Power between West Point and the intake point for Fort Benning's water supply, but these dams are run-of-river projects so Georgia Power has relatively little operational control over how much water flows downstream (Kent 2010).

Both human and natural systems water withdrawals alter the river flow between West Point and Fort Benning. A number of communities depend on the river for water supply; these withdrawals and returns affect the amount and quality of the water that makes its way south to Fort Benning. Additionally, both precipitation and evaporation affect flow levels along the river; these two factors are combined into a net runoff value.

As stated above, the proposed intake point for Fort Benning's water supply is just downstream from where Upatoi Creek empties into the Chattahoochee. The nearest stream gage to this point on the river is several miles upstream from the intake point at US 280 near Columbus. Though this is relatively close to the proposed future intake point, it does not capture the affect of flow from Upatoi Creek on the river. Data regarding the Upatoi

are available from a stream gage along Upatoi Creek slightly upstream from its convergence with the Chattahoochee.

#### *Drivers for water supply*

##### 1. Release through West Point Dam

West Point Dam, which creates a bottleneck along the Chattahoochee, is an important determinant of downstream water flows. The dam was built in the mid-1970s for the purposes of flood control, hydroelectric power, navigation, fish and wildlife development, and general recreation. The reservoir behind it extends upstream for 35 mi and has a maximum capacity of 605,000 AF. USACE operates the reservoir to maintain reasonably constant water levels, with lower levels during flood storage drawdown in winter and higher levels in response to periods of high inflow (Tetra Tech 2010, US Army Corps of Engineers 2002). Accordingly, discharge rates are higher during winter months during the heavy rainfalls at the beginning of the year (Figure 8).

The minimum instantaneous release from West Point Dam is supposed to be 675 cfs, though there are days when the average dam discharge dips below that number (Jordan, Jones, and Goulding 2009). Average daily dam discharges failed to meet that minimum on 44 days in 2009 and on 6 days in the first 3 months of 2010 (US Army Corps of Engineers Mobile District 2010). The average deviation from the minimum on those days was roughly 46 cfs. In 2009, failure to meet the minimum flow seemed to occur more often on summer weekends, possibly because the hydroelectric plant does not always operate on weekends.

Even with these days of below-minimum flow, the long-term (1976-2009) average discharge from the dam is roughly 4761 cfs. Over the approximately 35 years of its operation, the lowest average daily discharge over the course of a year was 2022 cfs in 2008 during the recent drought, and the highest average daily discharge was 7142 cfs, in 2003. There is a very slight decreasing trend in dam releases between 1976 and 2009, and dam releases during drought years (e.g., 2006-2008) tend to have a lower flow rate than dam releases during non-drought years (Figure 9).

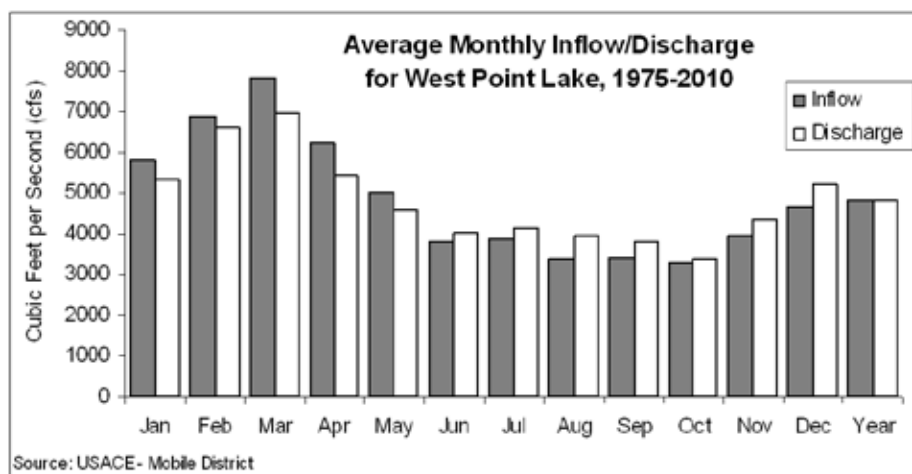


Figure 8. Average monthly inflow/discharge for West Point Lake (1975-2010).

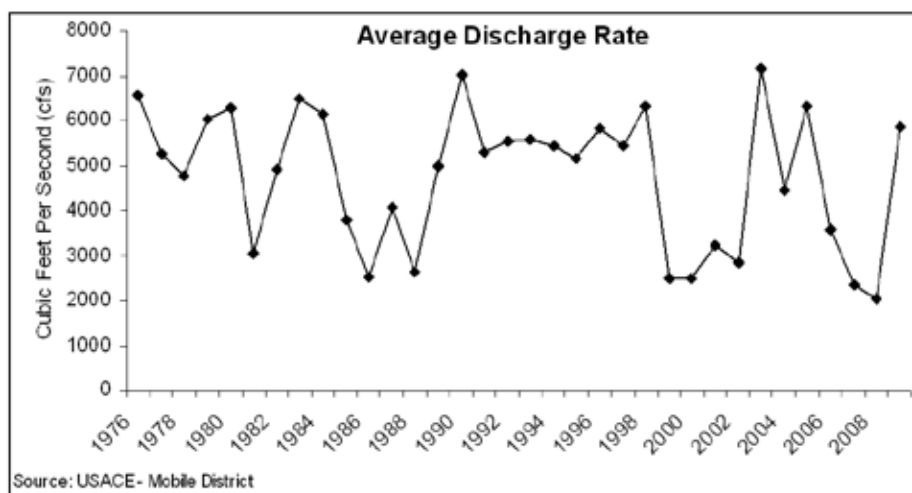


Figure 9. Average discharge rate — West Point Dam (1976-2009).

## 2. Water withdrawals/returns

Water withdrawals from and returns to the regional watershed also affect water availability at Fort Benning. Historical water withdrawal data are made available at the county level from USGS for the nation as a whole every 5 years. In 2005, upstream water withdrawals from within the watershed were estimated to be about 70 MGD (USGS 2009).

While extensive records are kept on water returns to the river by the individual utilities and industries that make these returns, there is no comprehensive record of all the returns to the river by area users. Columbus Water Works, which supplies water to both Fort Benning and the city of Columbus, estimates that between 80 and 85 percent of the

water they withdraw is returned to the river (Kent 2010). This figure is consistent with the amount of water reported returned to the river by the Metropolitan North Georgia Water Planning District once inter-basin transfers are factored out (AECOM 2009).

### 3. Runoff

Runoff is water from precipitation that does not infiltrate or evapotranspire, but may instead eventually reach a water body such as the Chattahoochee River. Including runoff as a driver for regional water supply thus allows for the inclusions of both elements (precipitation and evapotranspiration) in the water budget.

The regional watershed spans approximately 2192 sq mi and includes a number of tributaries. Average precipitation is generally higher than evapotranspiration in this part of the country, although that can be reversed during the Summer thus creating a water deficit. This normal variation in precipitation is reflected in lower streamflow during the Summer versus the Winter.

Figure 10 shows seasonal variation in streamflow at Columbus. The increased flow into the river attributable to precipitation is roughly accounted for by looking at the difference in flows between the dam release and the flow at Columbus once consumptive use has been subtracted. This value is assumed to be equal to runoff.

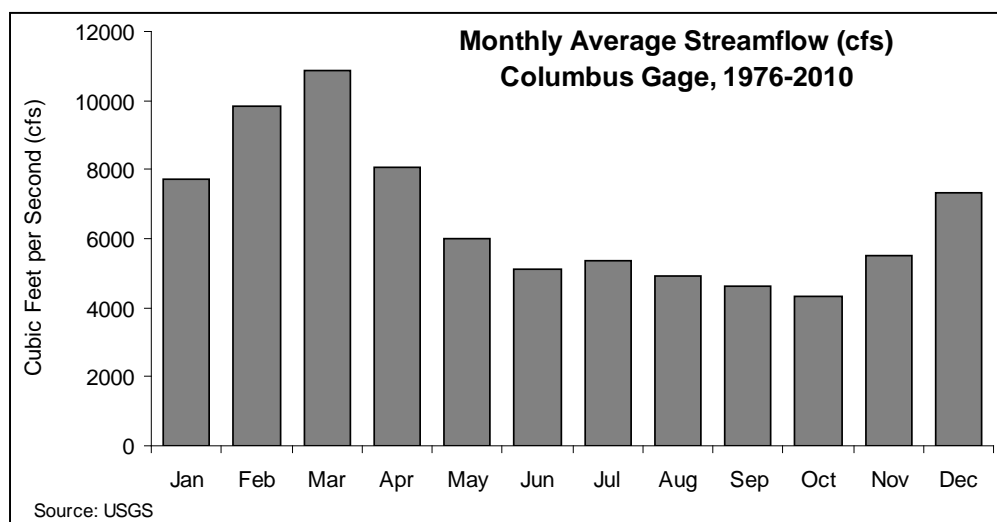


Figure 10. Monthly average streamflow – Columbus Gage (1976-2010).

Flow at Columbus has been recorded since 1929 at one of two different points along the Chattahoochee River. Currently there is a USGS gage at Route 280. This gage replaced the previous one, which until 2001 was located approximately 3670 ft upstream, but was removed due to problems with data collection at the site (Kent 2010). While some small amount of water is added to the river between the two gage sites, the amount is marginal; for the purposes of this study, the data collected at the two sites are considered a continuous source of streamflow data along the Chattahoochee River at Columbus.

The long-term average streamflow at Columbus between 1976 and 2009, after West Point Dam became operational, is roughly 6597 cfs. Over these years, the minimum average daily streamflow was 2929 cfs in 2008 and the maximum average daily streamflow was 9704 cfs in water year 2003, with 9704 cfs. Streamflow during drought years (e.g., 2006-2008) tends to be less than streamflow during non-drought years (Figure 11).

#### 4. Flow from Upatoi

While the closest gage along the Chattahoochee to the proposed future intake point for Fort Benning's water supply is at Columbus, there are a number of creeks that empty into the river after the gage point at Route 280. The largest by far, Upatoi Creek, has a stream gage located close to its confluence with the Chattahoochee, which can help to account for the additional inflow from this tributary.

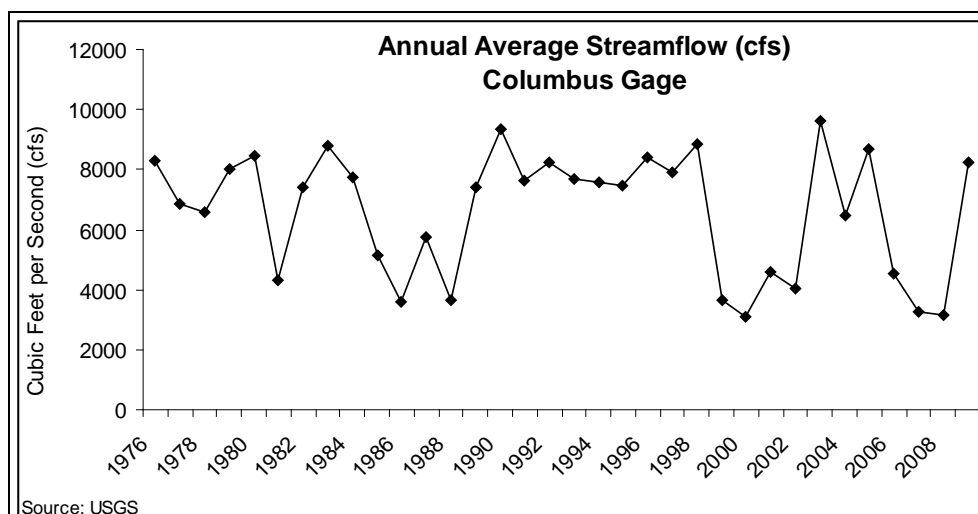


Figure 11. Annual average streamflow – Columbus Gage – 1976-2009.

Unfortunately, the gage along the Upatoi has only been in place for 1.5 years so there is a relatively short period of record available for this analysis. Streamflow over that period has averaged at 975 cfs, though it has dipped far below that level during summer periods when precipitation is low.

#### 5. 7Q10 flow

The 7Q10 flow at Columbus was calculated to be 1300 cfs using the USEPA's Dflow program and long-term streamflow at Columbus. However, the 7Q10 flow at the Fort Benning water withdrawal intake point is slightly greater due to the inflow of water along the Upatoi. Not enough data exist to calculate the 7Q10 of the Upatoi. As a best possible guess, the lowest 7-day average flow recorded along the Upatoi — 68 cfs — will be added to the 7Q10 at Columbus to approximate the 7Q10 at Fort Benning. Thus, 1368 cfs was used as the estimated 7Q10 at the proposed withdrawal point for Fort Benning.

#### 6. Interim Instream Flow Policy rule

The additional flow rule to be examined from the Interim Instream Flow Policy will be 30 percent of the mean annual average flow.

### **Regional water demand projection\***

The water demand projection actually consists of two separate projections — a projection of water demand for the region upstream of Fort Benning and a projection of water demand for Fort Benning itself. In each case, the projection establishes a contemporary baseline water withdrawal amount and then combines that baseline data with information about expected growth to predict withdrawal levels for 2040.

The water demand projection for the seven county region containing Fort Benning uses USGS water-use data from 2005 as a baseline and incorporates population projections for the selected counties (see Table 1 [p 17], above for more information regarding the population projections). The 2005 data were chosen even though 2005 was a relatively wet year because there were clearly shifts in how water was used over that time —

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\* The regional water demand projection does not include Fort Benning's projected demand, which is calculated separately. See "Fort Benning water demand projection" section (p 22).





Table 4. Fort Benning upstream regional water demand projection results (calculated).

	2010	2015	2020	2025	2030	2035	2040
Chambers	5.91	6.05	6.19	6.24	6.26	6.28	6.29
Chattahoochee	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harris	12.11	13.13	14.95	14.95	15.75	16.56	17.36
Troup	1.36	1.62	1.82	1.82	1.91	2.01	2.11
Lee	7.98	8.46	8.83	9.14	9.43	9.71	9.99
Muscogee	34.60	36.56	37.07	37.50	37.97	38.44	38.92
Russell	11.59	12.09	12.28	12.43	12.56	12.70	12.83
Total	73.56	77.91	80.18	82.07	83.88	85.69	87.50

### Fort Benning water demand projection

The Fort Benning Water Demand Projection uses data on historical water usage, real property, planned construction, and population projections for the installation to predict future water use. Water use is predicted by category of building, for example, family housing, industrial, and storage. The installation does not have individual building water meters at present, building level water factors collected by Billings and Jones (2008), were used to predict the amount of water used per building — or in the case of barracks and family housing, per resident. Local evapotranspiration is also taken into account to help predict water usage for irrigation.

Water-intensity use reductions are not incorporated into the Fort Benning water demand projection because the installation is moving towards reducing water use to meet the requirements of EO 13514 by switching to a privatized water supply (Duck 2010). Fort Benning's water demand projection stays relatively stable after 2016 — the extent of the planning horizon for the Army-provided data used in this projection. In all, Fort Benning's water demand is expected to increase by 44 percent, from 4.31 MGD in 2009 to 6.20 MGD in 2016. At the same time population and square footage will also have increased. If population growth and buildings stay at the 2016 level into the future, Fort Benning is expected to maintain a demand of roughly 6.20 MGD through 2040. Using a peak factor of 2.5, consistent with the CWW flow projections, which chose 2.5, a USACE design criteria, in conjunction with the Garrison Commander, this translates to a peak demand of 15.50 MGD expected for 2016 and onward.

### **Columbus Water Works water demand projection**

Although this study uses the above water demand projections from the Fort Benning Installation Demand Projection exclusively to forecast a final regional-level water demand, it is important to note that they do differ from previously developed installation-level water demand projections. The water demand projections created for this study are significantly lower than are the projections prepared by CWW for Fort Benning. CWW predicts a daily demand of 10.3 MG by 2012 and 11.9 MG by 2030. There are a number of reasons for this major difference, some of which are highlighted below to help the user make as informed a decision as possible regarding, which set of projections to use. These reasons include:

1. Differences in assumptions regarding population and population growth - Both the above water demand projections and the CWW water demand projections use population data provided by Fort Benning, but the population data used come from distinct sources and are very different, especially over time. CWW's water projections are based on numbers for the on-post design population for Fort Benning provided by the BRAC project manager in 2007. The water demand projections presented in this analysis used data regarding the numbers of housing units from the fourth quarter 2009 Raptor Population Index (RPI) and population data from the Army Stationing and Installation Plan (ASIP) from November 2009. In addition current and anticipated occupancy rates were used drawing on discussions with Fort Benning Directorate of Public Works (DPW) representatives and the RCI Program Manager in March 2010. The population figures (Table 5) are very different and diverge through time. This occurs because the ASIP (HQDA 2009) does not predict any changes in installation population more than 5 or 6 years into the future. While the population estimates used by CWW predict ongoing military population growth, the population estimates for this study predict growth leveling off by 2015.
2. Differences in assumptions regarding baseline water usage/water demand -The water demand projection prepared for this study used actual Fort Benning water use data from 2006 through 2009 to calibrate a baseline of water use for the installation that was then used to predict water use in future years. The baseline chosen for the Fort Benning water use projection was 5.19 MGD. CWW based the water demand factor used for its water demand projection on an evaluation of Fort Benning population and water consumption performed by Paul B. Krebs and Associates, Inc (CWW 2009). The water demand factor used by CWW in its projection was 150

gallons per capita per day (gpcd); in contrast, the average per capita daily water usage on Fort Benning in 2008 reported by CWW — which is roughly equivalent to this study's baseline — was 106 gpcd (note: in 2008 Fort Benning's average demand was 5.2 MGD).

3. **Differences in methods of projection.** The method used to project water demand in this study is also very different from the method used by CWW to project water demand. CWW projected water demand by applying the water demand factor described above (150 gpcd) to future population estimates for Fort Benning provided by the BRAC project manager. The water projection derived for this study estimated a number of different water demand factors for different building types and then used these factors in conjunction with real property and population estimates to predict future water demand.

In Table 5, the population assumptions and final projections for both this study and the CWW study are contrasted, making clear the differences between the two. Additionally, the study projections are adjusted to mimic the assumptions used in the CWW water demand projections to provide an idea of what this study's method would predict under the assumptions used by CWW. First, the population estimates used by CWW are input into the study population projection (see results in "Study: Population Adjustment" column in Table 5). This alteration yields a notable bump upwards in projected demand, however the projections remain far below those of CWW.

**Table 5. Study and Columbus Water Works water demand projections.**

	Population		Projection (MGD)			
	Study*	CWW	Study	CWW	Study: Population Adjustment‡	Study: Population + Baseline Adjustment
2008	49,334	49,152	5.2 (actual 2008 usage)			
2012	51,990	68,901	6.0	10.3	6.4	9.1
2030	60,984†	79,533	6.2†	11.9	7.3	10.3

\* From ASIP data, includes total military plus military family members — assumed to be equivalent to the on-post design population used by CWW.

† Identical to estimates from 2016 onward as there are no planned changes to assumptions after that year.

‡ CWW's population estimates include on-post design population (assumed to be equivalent to the sum of total military and total military family members). In addition, the study projection uses the number of full-time civilians; for consistency, this estimate was also adjusted upward by the same factor applied to the other population categories.

Source: CWW Water Demand and Wastewater Flow Projections (CWW 2009)

Next, the already altered water demand projections are further adjusted upward by a factor of 1.42 to attempt to account for the difference in baselines chosen (see results in “Study: Population + Baseline Adjustment” column in Table 5). This factor was chosen because the water demand factor used by CWW (150 gpcd) is roughly 42 percent greater than the 2008 baseline per capita water usage (106 gpcd). This adjustment results in water demand projections that are much closer to, but still lower than, the CWW water demand projections. The remaining difference between the two sets of projections can be attributed to differences in methods used to calculate the projections.

### Combined demand projection results

Figure 12 shows the combined results of the regional water demand projection and the installation water demand projection created for this study. CWW’s projections are not used. The population of the region as a whole is expected to increase demand from 75.3 MGD in 2007 (the earliest year for which data from Fort Benning are available) to 93.7 MGD in 2040. This represents an increase of 24 percent. If water efficiency best management practices were put into effect for the entire upstream region, the total withdrawals and consumptive usage could be reduced.

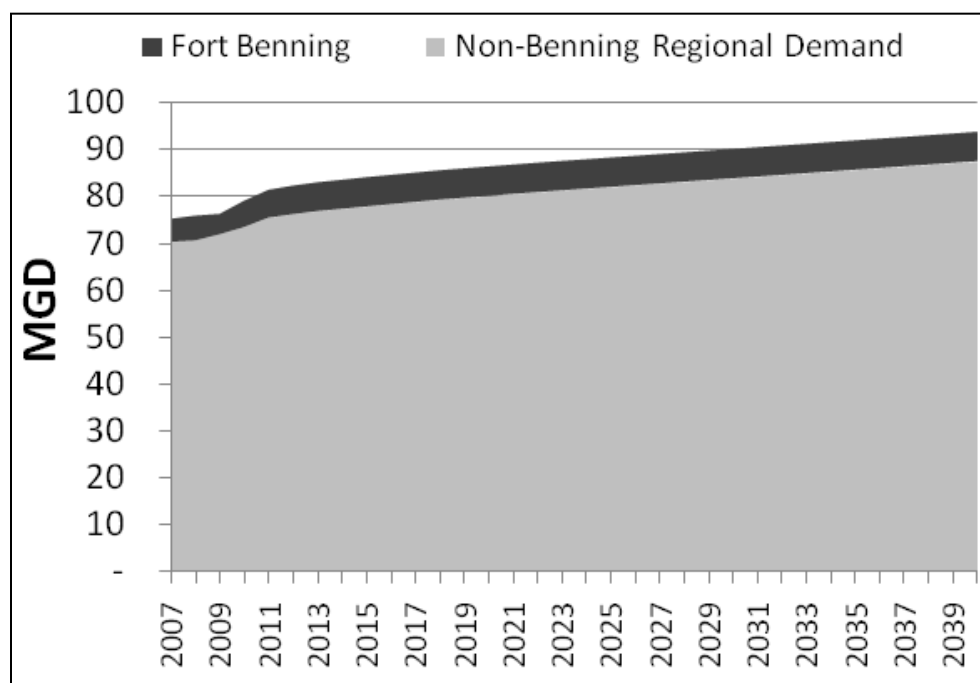


Figure 12. Fort Benning regional demand.

## Fort Benning 2040 water availability scenarios

The objective of this study was to project water availability 30 years into the future. Therefore the baseline water supply and demand were projected to the year 2040. The potential for water scarcity was reviewed under alternate scenarios to better account for future uncertainty.

### Scenario 1 — Status quo

Scenario 1 represents a water supply outcome in which current trends continue into the future bringing only gradual change to the water availability situation. Population growth is assumed to continue at the expected rates, and climate change is assumed to affect the water situation minimally.

Projections of climate change for the southeastern United States vary widely from less rain to more rain, but they all show an increase in temperature. A weighted average of 17 different Global Circulation Models (GCMs) shows that an increase in both rain and temperature for the region should be expected (Cai et al. 2008).

Increased rain will increase river flow, whereas increased temperature will decrease river flow due to increased evaporation. This makes predicting the effect on river flows extremely difficult. Therefore, Scenario 1 assumes that, while the temperature increases do result in lower low-flows, the precipitation increases offset those low flows over the course of a year. So there is no change to net runoff to the river. Therefore, change in average water availability is driven mostly by changes in demand for water from the river basin — within the region these are predicted by the installation and regional demand models.

Upstream of West Point Lake, users from the greater Atlanta metropolitan area do use water from the basin, although the portion of water added to the basin below Atlanta's withdrawals is significant due to precipitation. The extent of future water withdrawal from the Chattahoochee River by the greater metropolitan Atlanta area is uncertain. The region is actively pursuing a variety of water sources beyond Lake Lanier both within and outside of the Apalachicola-Chattahoochee-Flint river basin; however, it is likely that regardless of whether the city continues to draw water from Lake Lanier itself, the ACF-basin will still be tapped. Despite this, pressure from downstream users on the metro region is unlikely to wane and there

is likely to be a great deal of opposition to any significant increase in the area's withdrawal of water from the ACF-basin in the current legal/political environment. This scenario therefore assumes that increases in water use upstream of West Point from the Chattahoochee River are either directly limited or indirectly offset by an increase in water returns to the basin. Thus, this scenario predicts only a very slight decrease to the amount of water released from West Point Dam over the coming years.

### **Scenario 2 — Climate change brings recurrent drought**

Scenario 2 explores the possibility that, as a result of climate change, the larger region begins to experience recurring droughts. The most recent US Global Change report on climate change suggests that “decreased water availability due to increased temperature and longer periods of time between rainfall events” was likely for the Southeast (US Global Change Research Program 2009). This scenario investigates how the low-flow periods between rainfall events may manifest themselves. Such a scenario may be more likely to represent not average streamflow, but a low-flow period of perhaps a year in length along a spectrum of streamflow variability. In that case, a reasonable possibility for future water availability to the region surrounding Fort Benning would be oscillation between the water futures proposed in this and the previous scenario.

For this scenario, dam releases and decreases in runoff are set roughly equivalent to those experienced in this region during 2007. Demand is derived from the regional and installation demand models, though consumptive use is expected to increase slightly as users increase consumptive water use to offset the precipitation deficit. Finally, low flows are set to decrease at half the rate of the decrease in runoff.

### **Scenario 3 — Greatly increased demand**

This scenario explores the possibility that future demand will be considerably more than in the status quo scenario, both from West Point Reservoir, and below the dam's release point and from Fort Benning. This scenario proposes that, starting in 2012, the demand for water from West Point Reservoir will increase by 100 MGD and that this additional demand will grow by 2.5 percent each year. One hundred MGD was chosen because it is the amount proposed to be pumped from West Point Reservoir to the metro-Atlanta region in the wake of Judge Magnuson's ruling to keep all

pumping from Lake Lanier below 1970-levels. The 25 percent growth rate every 10 years is meant to mimic metro-Atlanta's growth pattern in the early 2000s. This is an especially high estimate because it does not account for the 100 MGD that would presumably *not* be pumped out of Lake Lanier, though more than 100 MGD would have to be pumped from West Point Lake to replace water from Lake Lanier given increases in water loss over the longer distance. Furthermore, West Point Reservoir is not currently authorized for water supply at all, and there is significant pressure against reauthorization, making this specific sort of an increase unlikely. Nonetheless, such an increase in water use from West Point Lake is the maximum plausible increase in use.

Regional water demand is also assumed to increase by an amount greater than the regional demand projection. For the purposes of this scenario, it is assumed that water demand at the regional level between now and 2040 grows at a rate 1.5 times that currently projected. Such growth could be attributed to significantly greater population growth than is expected, the addition of a water-intensive industry to the region, or both.

Water demand for the installation itself in this scenario was estimated using the population estimates used by CWW in its water demand projection (see "Fort Benning water demand projection as it compares to "Columbus Water Works water demand projection" [p 36]). The population estimates CWW obtained from Fort Benning were significantly higher than the population estimates obtained for this study.

#### **Scenario 4 — Recurrent drought with greatly increased demand**

This scenario presents a worst-case scenario — combining the natural decrease in supply and human increase in demand stipulated in the previous two scenarios. Thus, it is assumed the amount of water released from the dam in a given year is equal to the amount released in the drought scenario less the additional pumping discussed in the increased demand scenario. Below the dam, runoff and low flow are set equivalent to runoff under a drought scenario and basin demand is set equivalent to the demand from the greatly increased demand scenario.

### **Scenario 5 – Regional water efficiency in a recurrent drought situation\***

This scenario takes the recurrent drought conditions of Scenario 2 and proposes that the region work together to decrease water demand. This decrease in water demand is achieved by increasing the efficiency of water use while reducing leaks and waste through cost-effective water-saving technologies, revised economic policies, and state and local regulations. Sustainable management plans are created to help reduce water consumption based on changes in the water system. Strategic intervention initiatives used in this scenario are a Public System Loss Management Program initiated in 2011, a Commercial/ Industrial Water Conservation Program initiated in 2013, a Residential Water Conservation Program initiated in 2016, and an Agricultural Water Conservation Program initiated in 2019. Water reuse was not considered as an option for this analysis as that would require the development of a separate distribution system.

The Public System Water Loss Management Program consists of a 50 percent reduction in losses over 2 years through a leak detection and remediation program. The Industrial Program consists of an approximate 39 percent reduction in usage over 8 years with 90 percent market penetration through a water conservation program. Traditional heavy industries could lower their water use by three-quarters by replacing large volumes of cooling and process water with recycled and reclaimed water. Other industries that could save large portions of water include paper and pulp, commercial laundries, and schools. The Residential Program is meant to achieve 39 percent reduction in use in older homes starting in 2016 over an 8-year phase-in with 90 percent market penetration. Even without improvements in technology, an almost 40 percent reduction in water use is estimated to be possible by replacing inefficient appliances and reducing leaks. In addition, a policy change requiring new homes to include ultra low flow toilets and showerheads is implemented in 2016 with 100 percent penetration since it is code. The Agricultural Program consists of a 50 percent reduction in usage over 10 years starting in 2019 based on irrigation efficiency improvement and use reductions.

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\* The water efficiency program stipulated in this section is adapted from Gleick et al. (2003).



Table 6. Scenario results comparison (MGD).

	Baseline	Scenario 1: Status Quo	Scenario 2: Recurrent Drought	Scenario 3: Increased Demand	Scenario 4: Drought + Increased Demand	Scenario 5: Water Efficiency in Drought
Estimated flow at Columbus	3595	3556	1873	3368	1685	1879
Estimated flow at Benning	3840	3800	1978	3612	1789	1984
Difference from base-line flow at Benning	—	39	1862	227	2051	1856
Current law avail-ability at Benning	2956	3005	1347	2817	1158	1353
30% law availability at Benning	1152	1140	593	1084	537	595
Estimated Upstream Withdrawals	72	88	88	95	95	63
Estimated Benning Demand	5.19	6.20	6.20	7.65	7.65	4.63

### Scenario results

Table 6 lists the results of each scenario. While water availability in each of the scenarios is lower than the baseline, none of the scenarios predict a water scarcity outcome for either Fort Benning or the larger region when water availability is averaged over the course of an entire year. However, water does not flow at an average rate on each day in the year or even in each year in a decade. This is clearly demonstrated by the variability at the Columbus gage itself — ranging from an average of 2629 to 9704 cfs in a given year, flows peaking in March and bottoming out in October. Furthermore, while it is unclear how climate change will affect the average amount of precipitation to the area, it is expected to make that precipitation more variable, meaning that precipitation will occur in fewer, more intense storms.

It is important to keep this variability in mind when considering the future suggested under each scenario — an average daily decrease in flows from the baseline of 39 MGD (scenario 1) will have very different implications than a decrease of 1862 MGD (Scenario 2) in a low-flow water year.

Although these results are based on an analysis that uses the installation water-demand projection developed for this study and not the CWW water demand projections, it may be relevant that the scenario in which water availability at Benning is the lowest — Scenario 4 — still forecasts that more water will be available than CWW projects will be demanded by the installation. CWW projects that the installation's average daily demand will be between 11.9 and 14.4 MGD in 2040, whereas the lowest water availability projection for the installation suggests that over 500 MGD will

be available to the base, on average. Of course water flow variability would be of more concern should Fort Benning's daily average water demand increase to these levels. Thus, while a long-term water scarcity outcome is not likely for the installation, even under the sort of demands forecast by CWW, short-term water scarcity issues are very slightly more likely under these demands.

### **Water sustainability assessment for the Fort Benning region**

Overall, it is clear from these results that, compared to other regions in this study, the Fort Benning region is relatively water-rich. Nonetheless, the region is definitely at risk for short-term periods of water scarcity, and the severity of this scarcity varies by scenario. It seems that natural conditions play a bigger part in water availability for the region than does human demand. Neither the increased demand scenario nor the water efficiency scenario yield changes to the overall water availability situation anywhere near as drastic as does the drought scenario. Unfortunately, droughts such as those proposed in Scenario 2, droughts experienced earlier this decade in the area, and perhaps even droughts of worse intensity are expected to fall into the range of normal variability in the future. In short, while there is little risk of long-term water scarcity for the region, droughts are likely to create short-term periods of scarcity in the future.

Luckily, the area's relative water-richness suggests that so long as Fort Benning and the region have enough storage, the area will be able to ride out periods of water scarcity through 2040, at least. Of course, that still leaves the question of "How much water is enough?" The answer to that question lies with: (1) a picture of how short-term water scarcity might play out across the region, which is outside of the scope of this study, and (2) with a picture of future water demand, which is wholly within the scope of this study.

While the water efficiency scenario changes overall water availability only very slightly, the affect it has on water demand under this scenario is substantial — 25 and 28 percent below expected 2040 demand for the installation and the region, respectively, in the absence of such measures. Managing water demand through the implementation of conservation and efficiency measures is widely accepted to be less costly than increasing water supply because for each gallon of water demand reduced, less water

storage will be needed for periods of low-flow. Demand management is the first line of defense against water scarcity and should be part of the approach to the anticipated short-term water scarcity situations in the future.

Additionally, if the region begins to experience more intense storms, as predicted by climate change models, embracing a regional level total water management approach would help to manage water more effectively under both low-flow and intense-storm extremes. Total water management works to manage all three water systems — water supply, wastewater, and stormwater — together to work toward a sustainable water supply. Keeping stormwater in the area for as long as possible, as opposed to pushing it downstream as quickly as possible, allows for it to be tapped as a potential water supply. Fort Benning is already beginning to do this: stormwater is used as a water supply for at least one of its vehicle washes.

Because of the risk for short-term water scarcity, this report recommends that Fort Benning and the region begin planning for increasingly extreme drought-flood cycles through the gradual implementation of demand management and total water management practices. At the installation level, demand management practices should be pursued as funding sources become available. Drought contingency plans should also be prepared in anticipation of periods of future short-term scarcity. The sooner these measures are implemented, the sooner the installation will be able to respond to an emerging drought situation. Implementing an on-installation stormwater management program will help prepare the installation for fluctuations in water availability while easing the effects of extreme storm events and increasing water security and independence in the future.

## 4 Fort Campbell, Kentucky and Tennessee

Founded in 1942, Fort Campbell is one of the Army's power projection platforms. With 106,000 acres that straddle the Tennessee-Kentucky state line, Fort Campbell is home to the only air assault division in the world, the 101st Airborne Division (Air Assault). It is also home to two Special Operations Command units, the 5th Special Forces Group (Airborne) and the 160th Special Operations Aviations Regiment (Airborne), and the 86th Combat Support Hospital, 716th MP Battalion, and significant medical and dental care activities (Fort Campbell 2009).

In 2003, approximately 25,300 Soldiers and civilian workers were stationed at Fort Campbell. Army transformation initiatives will bring this number to 30,504, and by 2013, Fort Campbell is projected to have over 31,200 Soldiers and civilian workers. The population growth in this 10-year period amounts to an increase of about a third over the 2003 population (Balocki 2008).

Fort Campbell spans four counties: Christian and Trigg counties in Kentucky; and Montgomery and Stewart counties in Tennessee. These four counties make up the Clarksville, Tennessee-Kentucky metropolitan statistical area (MSA). The MSA has seen rapid growth since 1970 (Figure 13). In 2009, the estimated population of the Clarksville, TN-KY MSA was approximately 269,000 (US Census Bureau 2010).

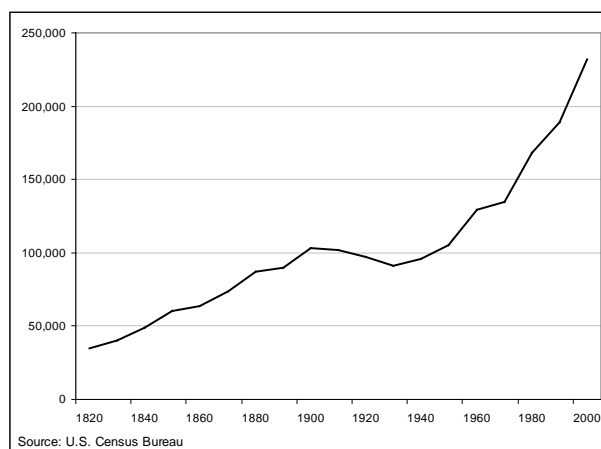


Figure 13. Historic population growth in the Clarksville, TN-KY MSA.

## Regional characterization of Fort Campbell

The following sections describe the natural and human systems that define the Fort Campbell region and influence development and outcomes of the regional water balance.

### Demographic trends

The Clarksville, Tennessee-Kentucky MSA includes the cities of Hopkinsville and Cadiz, KY. The eastern portion of Fort Campbell borders the city of Clarksville, which in 2009 had an estimated population of about 120,000 (US Census Bureau 2009). The city of Nashville, TN is approximately 60 mi southeast of Fort Campbell.

Figure 14 shows a map of the Fort Campbell area. The Fort Campbell regional population is expected to grow faster than the Kentucky, Tennessee, and US averages for the next 20 years. The population of the four-county Clarksville, TN-KY MSA is projected to grow to almost 350,000 by 2030, an increase of 50 percent over the 2000 population.

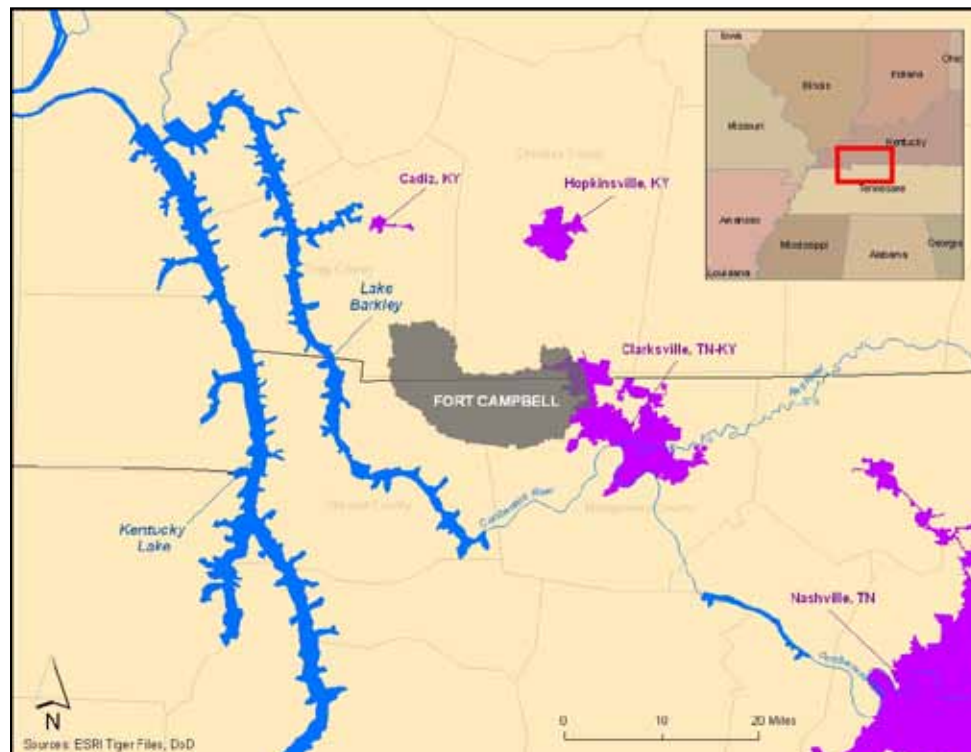


Figure 14. Location of Fort Campbell.



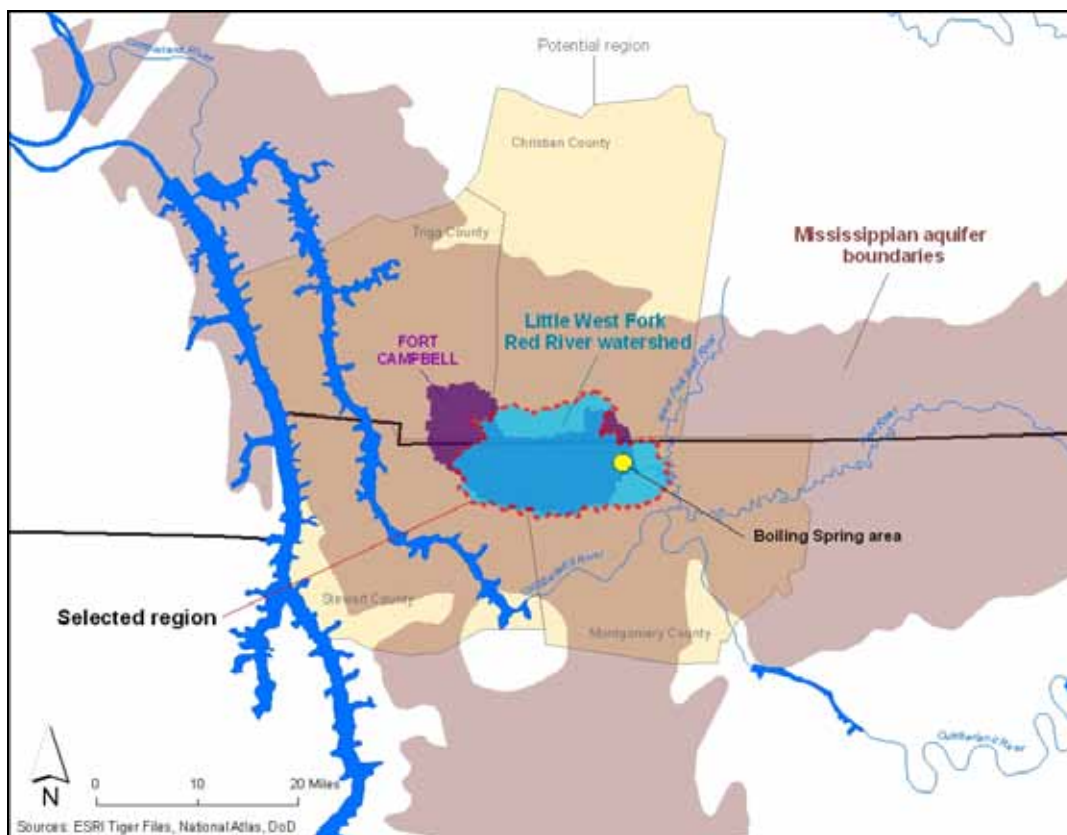


Figure 15. Fort Campbell study region.

### Water sources

Fort Campbell relies primarily on water from Boiling Spring, a large spring source on the Tennessee portion of the post that arises from limestone rock (Webbers 1995, and Fort Campbell Directorate of Public Works 2009). The spring is located next to the Little West Fork of the Red River, a major tributary of the Cumberland River. The area surrounding the spring has been designated a Wellhead Protection Area. Fort Campbell has a 16-in. raw water source (Red River) from the city of Clarksville that could be used in the event it is needed. Additionally, Fort Campbell has discussed options with both the city of Clarksville, TN and the city of Hopkinsville, KY for providing treated water to the post boundary (Fort Campbell Directorate of Public Works 2009).

The study region lies above limestone aquifers in Mississippian rocks. These aquifers have been termed the Mississippian Plateau aquifers and the Highland Rim aquifer system, and are located in Kentucky and Tennessee, respectively. Occurring in limestone that is either flat or gently

dipping, these aquifers are topped by a layer of chert regolith (a layer of loose, heterogeneous material covering solid rock) that can vary greatly in thickness. In some places in Tennessee, the regolith, which forms as the underlying bedrock weathers, is as many as 150 ft thick and can contain large quantities of water. The limestone aquifers that yield the most water to wells and springs are the Upper Mississippian Monteagle, the Ste. Genevieve, and the St. Louis Limestones. All three of these limestone aquifers are present in west-central Tennessee.

Mississippian aquifers are recharged mainly through precipitation that permeates the land surface and percolates downward to the water table, which marks the top of the saturation zone. The water then moves through intergranular spaces in the regolith. Once it reaches the underlying limestone bedrock, it moves through permeable areas created by dissolution and enlargement of the bedding planes, and through fractures created by the slightly acidic water. These permeable areas store and convey most of the water that moves through the limestone aquifers and discharge to streams, springs, and wells.

Water in limestone aquifers may be as deep as 500 ft below the land surface, but most is at depths of less than 300 ft. Little to no regional groundwater flow occurs in Mississippian aquifers. Most flow is local and drains towards the springs and few streams in the area. This localized flow is complex, with many horizontal and vertical components.

Well and spring yields in the region differ greatly over short distances due to the varied hydraulic characteristics of Mississippian aquifers. Well yields generally range from 2 to 50 gallons per minute (gpm), but some wells in Illinois have been reported to provide over 1000 gpm. Additionally, spring discharges usually vary from about 3 to 1100 gpm. Boiling Spring reportedly discharges about 5 million gallons of water per day, on average more than 3000 gpm (Fort Campbell Directorate of Public Works website). However, it is not known how much water is available in the Mississippian aquifers in the Fort Campbell region (Lloyd and Lyke 1995).

The Cumberland River, which supplies water to Clarksville, is 688 miles long and has its headwaters in eastern Kentucky. It winds through southern Kentucky and northern Tennessee before draining into the Ohio River at Smithland, KY.



## Water rights and regulations

As a Federal military installation, Fort Campbell is not subject to state water rights laws. However, the city of Clarksville, which is immediately adjacent to the base and is a potential water supplier, is subject to Tennessee regulations.

Both Kentucky and Tennessee use riparian doctrine to establish water rights (Johnson 2009). Both states are considered to be “regulated riparian” states, although Tennessee is less so because it has generally avoided the types of conflicts that have led to increased regulation in neighboring states like Kentucky. The law governing water withdrawals in Tennessee is therefore almost entirely common law, and there has been very little legislation governing water use in the state.

Generally, water rights in Tennessee depend on the location of the water and whether it is confined. The state has slightly different rules for groundwater versus surface water. Although difficult to prove, if groundwater can be shown to flow in an underground stream channel, then it is treated as surface water. Since this is difficult to prove, most groundwater is treated as diffuse, which can be either diffuse groundwater or diffuse surface water. Diffuse groundwater is water confined in an aquifer or percolating through the ground, while diffuse surface water is runoff from precipitation. Anyone in Tennessee may capture precipitation and runoff, but legal issues arise when one landowner diverts or channels the water from his land in a way that causes damage to another person’s property.

Tennessee does not manage surface and groundwater conjunctively, meaning that it does not manage and develop water resources in a manner that recognizes the interconnectedness of surface and groundwater in the hydrologic cycle. The entire basis for groundwater law in Tennessee is a single case, *Nashville, C. & St. L. Ry. v. Rickert*, which held that Tennessee groundwater rights are correlative to the rights of other landowners’ reasonable use of the same aquifer. Under the correlative rights doctrine, there is no quantification of water rights, no priority of uses, and no lawful use of water off overlying land or outside the recharge basin. However, the *Rickert* case did not raise these issues so they remain uncertain (University of Tennessee Energy, Environment, and Resources Center 2010).

Tennessee does have a Division of Water Supply, which monitors pumping and administers the state's wellhead protection program. The Groundwater Protection Division primarily monitors onsite wastewater disposal to prevent contamination of groundwater. The Cumberland River Compact, formed in 1997, charges itself with protecting the environmental health of the Cumberland River basin.

### **Climate**

The average annual temperature in Clarksville is 69 F. The coldest month is January, with an average of 27.9 F, and the warmest is July, which has an average temperature of 88.7 F. Average annual precipitation is about 48 in.

### **Topography**

Fort Campbell is located in karst topography with numerous sinkholes, caves, sinking streams, and underground rivers (Fort Campbell 2010).

Lake Barkley and Kentucky Lake are west of the installation (cf. Figure 5, p 15). Lake Barkley is one of the world's largest man-made lakes and is located on the Cumberland River. The lake, managed by the Nashville District of the US Army Corps of Engineers (USACE), provides outdoor recreation activities for millions of visitors every year (USACE Nashville District 2010). Also one of the world's largest man-made lakes, Kentucky Lake was created in 1944 when the Tennessee Valley Authority (TVA) built the Kentucky Dam on the Tennessee River. The area between the two lakes is known as the Land Between the Lakes National Recreation Area (Kentucky Lake 2010).

### **Land Use**

Most of the land cover in the study region is deciduous forest. The northern part of the region is largely cultivated crops. Developed land is concentrated in the eastern portion of the region where Fort Campbell's main cantonment area and the city of Clarksville are located. Spots of pasture, hay, and grassland also dot the study region. Figure 16 shows land use in the study region.

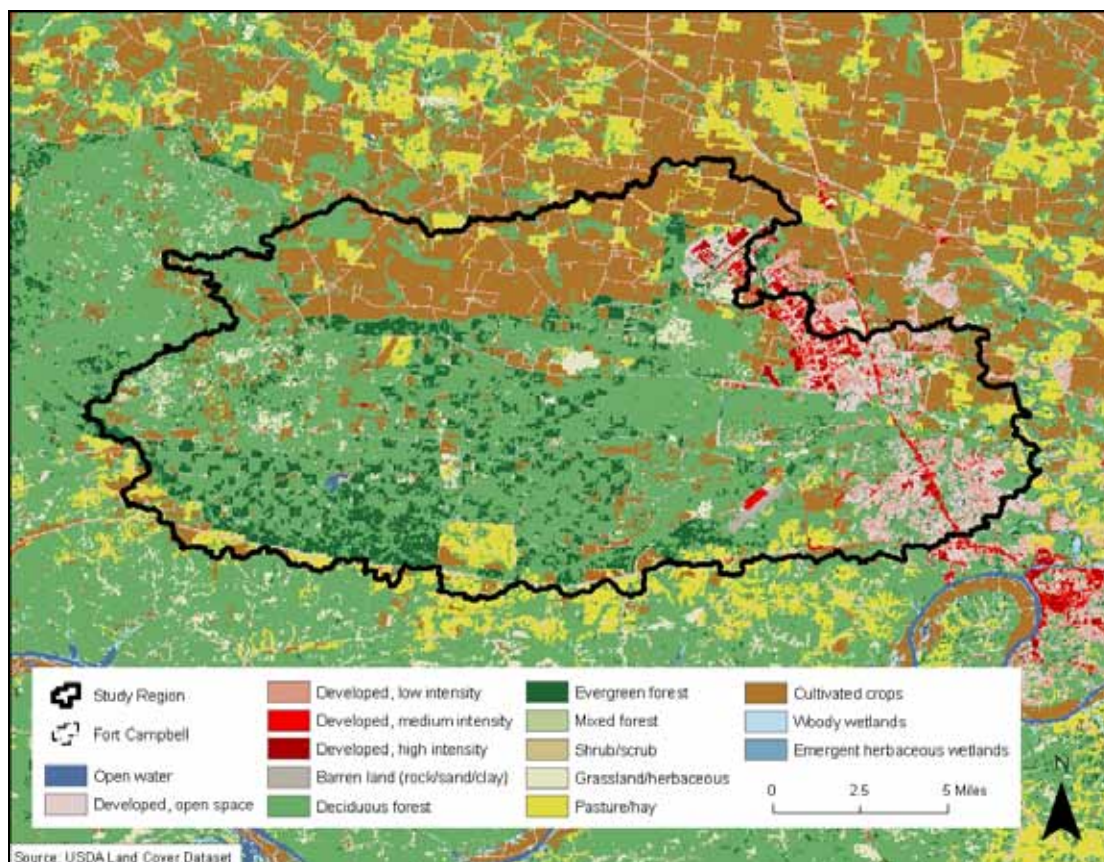


Figure 16. Land use in the Fort Campbell area.

### Historic water demand

Although Fort Campbell's water supply comes from a groundwater spring source, the four counties in the study region depend mostly on surface water. In 2005 groundwater made up only 0.6 percent of the estimated withdrawals for the study region. However, this was up from 0.1 percent in 1995. Groundwater withdrawals increased from 0.07 MGD to 0.74 MGD during that 10-year period. Of the four counties, Montgomery County is by far the most dependent on groundwater for its potable water supply. In 2005, almost 24 percent of its total withdrawals were from groundwater, as opposed to 1 percent or less for the other three counties. Stewart County is the largest user of water; its 2005 total withdrawals were over 2 billion gallons a day, most of which was for thermoelectric power generation (US Geological Survey 2009). Table 8 lists historical water use data for the MSA by county.

Table 8. Historical water use (in MGD) in the Fort Campbell area, by county (1985-2005).

		Christian	Trigg	Montgomery	Stewart	Total
Surface water	1985	6.02	1.47	12.40	1,779.91	1,799.80
	1990	6.18	1.55	11.32	1,649.20	1,668.25
	1995	9.76	2.20	24.82	2,196.36	2,233.14
	2005	14.28	6.00	18.46	2,075.74	2,114.48
Groundwater	1985	0.96	0.06	0.81	0.42	2.25
	1990	1.70	0.09	5.89	0.59	8.27
	1995	0.63	0.04	0.22	0.37	1.26
	2005	0.19	0.06	5.80	7.14	13.19
Total	1985	6.98	1.53	13.21	1,780.33	1,802.05
	1990	7.88	1.64	17.21	1,649.79	1,676.52
	1995	10.39	2.24	25.04	2,196.73	2,234.40
	2005	14.47	6.06	24.26	2,082.88	2,127.67
Source: USGS 2009						

Table 9. Estimated 2005 water withdrawals in study region.

	2005
Groundwater (MGD)	2.1
Surface water (MGD)	9.6
Total withdrawals (MGD)	11.7
Estimated population	69,197
Source: USGS 2009	

## Developing the Fort Campbell regional model

Fort Campbell currently obtains most of its drinking water from Boiling Spring, a spring source on post that can provide about 5 million gallons of water per day. Other groundwater withdrawals in the region are minimal, as the other major users of water in the area rely almost exclusively on surface water. Table 9 lists the 2005 water withdrawals in the region of study by ground and surface water.

### Water supply model

The year 2005 is used as the model's baseline year and supply is projected under several alternate future scenarios out to 2040. The model is analyzed at the HUC-12 level (sixth scale hydrologic units) drainage basin containing Boiling Spring.

*Mississippian aquifers in the Little West Fork Red River basin*

Fort Campbell's main source of potable water, Boiling Spring, is located next to the Little West Fork of the Red River. Past research found that the estimated mean recharge rate for aquifers in this area is 7.4 in. per year. Annually steady-state conditions predominate so the discharge generally equals the recharge and there is insignificant leakage from underlying aquifers (Hoos 1990).

*Drivers for water supply*

The main driver for water supply in the study region is the change in storage from recharge, evapotranspiration losses, and withdrawals. The non-Fort Campbell groundwater withdrawals were calculated by assuming that 36 and 21 percent of the populations of Montgomery and Christian counties, respectively, reside within the boundaries of the study area. Fort Campbell's estimated withdrawals were then subtracted from the sum of the estimated groundwater withdrawals of Montgomery and Christian Counties. Very little of the study area is in Trigg and Stewart counties so water withdrawals from those counties were considered insignificant to determine the overall water budget for Fort Campbell.

Past research on aquifers in the area determined that the net recharge rate for aquifers in the Fort Campbell area is 7.4 in./year (Hoos 1990) or 5.44 MGD when calculated for the HUC-12 level drainage basin containing Boiling Spring.

**Fort Campbell water demand projection**

The Fort Campbell Water Demand Projection uses historical water use data, current building stock, planned construction, and installation population projections to predict future water demand. Water use is estimated by building type (family housing, industrial, storage, etc.). Fort Campbell does not meter water data at the building level at present. The American Water Works Association building level water factors were used to predict the amount of water used per building — or in the case of barracks and family housing, per resident (Billings & Jones 2008). Local evapotranspiration is also taken into account to help predict water use for irrigation.

Fort Campbell's water supply projection incorporates a Federally mandated 2 percent decrease in total use every year until 2020, using 2007 as the baseline. The population at Fort Campbell is not expected to increase significantly in the period until 2020. Due to the required reductions in water use, water demand is projected to decrease from its current projected demand of 3.96 MGD to 3.01 MGD in 2020. Currently, no population load changes or construction/demolition projects are anticipated for the years past 2020. Thus, Fort Campbell is projected to maintain a demand of roughly 3.01 MGD through 2040. Figure 17 shows Fort Campbell's projected future demand both with and without the 2 percent annual water efficiency reductions.

#### *Water demand model*

The water demand projection for the Fort Campbell region is based on 2005 consumption and the population projections for the study region, which were calculated by multiplying the estimated 2005 population and population projections for Montgomery and Christian counties by 0.36 and 0.21, respectively (see previous section for explanation). Since the current Kentucky and Tennessee official population projections only extend to 2030, a linear trend is assumed from 2030 to 2040.

The region's estimated future withdrawals were calculated using the following method: the total estimated withdrawals in 2005 were divided by the 2005 population, resulting in a ratio of total population to withdrawals in gallons per capita per day (gpcd). For Montgomery County this ratio was 164 gpcd, and for Christian County it was 185 gpcd. These ratios were multiplied by the estimated population for each year up to 2040, assuming a 1-percent decrease in the gpcd value every year due to increased water efficiency. However, the model is constructed so that the user can easily alter the estimated change in gpcd. The model also assumes that the ratio of groundwater withdrawals to surface water withdrawals remains the same as in 2005, but this can also be adjusted.

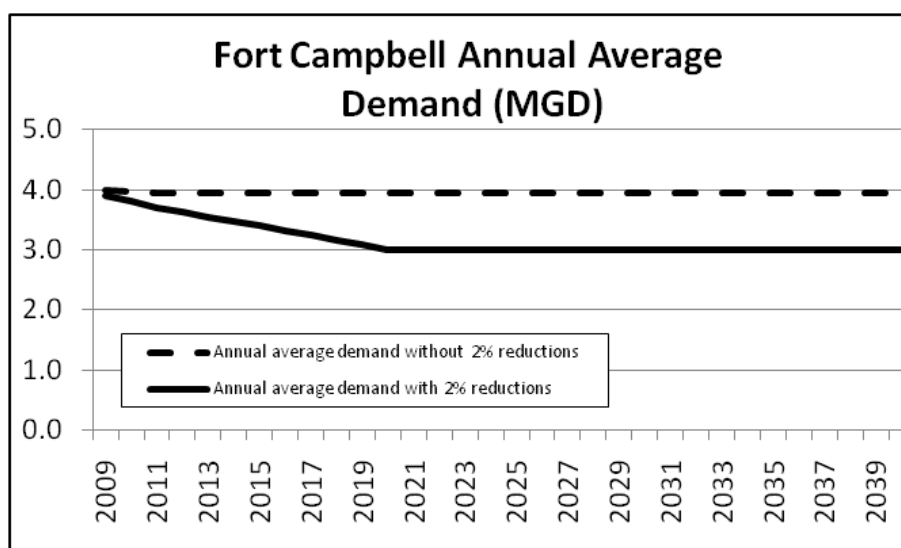


Figure 17. Fort Campbell projected water demand with and without 2 percent reductions.

#### *Model results*

Figure 18 shows the baseline projection for the region. Water demand is expected to decline in the coming decade despite continued population and industrial growth because water use for agriculture, mining, and live-stock will decrease. This trend reverses in 2020 due to the large increase in population expected in Montgomery County. This increase will overwhelm any water savings expected from increased efficiency.

The objective of this section is to project water availability to 2040 based on several alternate future scenarios. Therefore, the 2005 baseline is projected to 2040 for both the supply and demand models.

#### **Scenario 1 – Climate change**

The southeastern United States, including Tennessee and Kentucky, has seen increasing average temperatures since the 1970s and very strong increases in annual rainfall over the past century. The two primary models used to predict climate changes for the region are the US National Assessment on Climate Change (US Global Change Research Program 2009) and the Hadley and the Canadian models (USGCRP 2009). Both project that the region will experience significant warming by the 2090s. The Canadian model projects that the southeast will experience a high degree of warming, which will decrease soil moisture as higher temperatures increase evaporation.

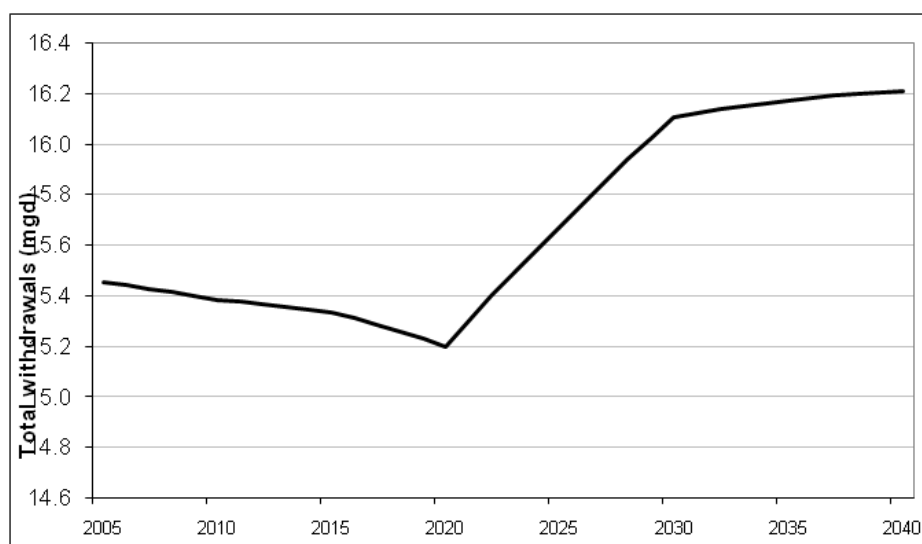


Figure 18. Baseline demand projection for Fort Campbell region.

### Fort Campbell 2040 water availability scenarios

The Hadley model scenario projects less warming than the Canadian model, but calls for a 20 percent increase in precipitation in the region. Some climate models indicate that rainfall associated with El Nino and the intensity of droughts during La Nina phases will be intensified as atmospheric carbon dioxide increases. Despite these projections of increased annual precipitation, the US National Assessment on Climate Change actually predicts that climate change will intensify existing stressors on the region's water supply, including urban development and agricultural activities. Thus, an increase in precipitation does not necessarily lead to an increase in the region's water supply (National Assessment Synthesis Team 2000).

This scenario assumes a 10 percent decrease in net recharge to aquifers in the Fort Campbell region based on the inability of existing infrastructure to capture the runoff associated with predicted increased rainfall, which is likely to be concentrated in extreme events. It assumes a 21 percent decrease in withdrawals by Fort Campbell by 2040 due to increases in water efficiency in compliance with E.O. 13514 (derived from the installation demand model) and a 16 percent increase in groundwater withdrawals by other users in the region by 2040 (derived from the regional demand model baseline scenario). Figure 19 shows the results of Scenario 1.



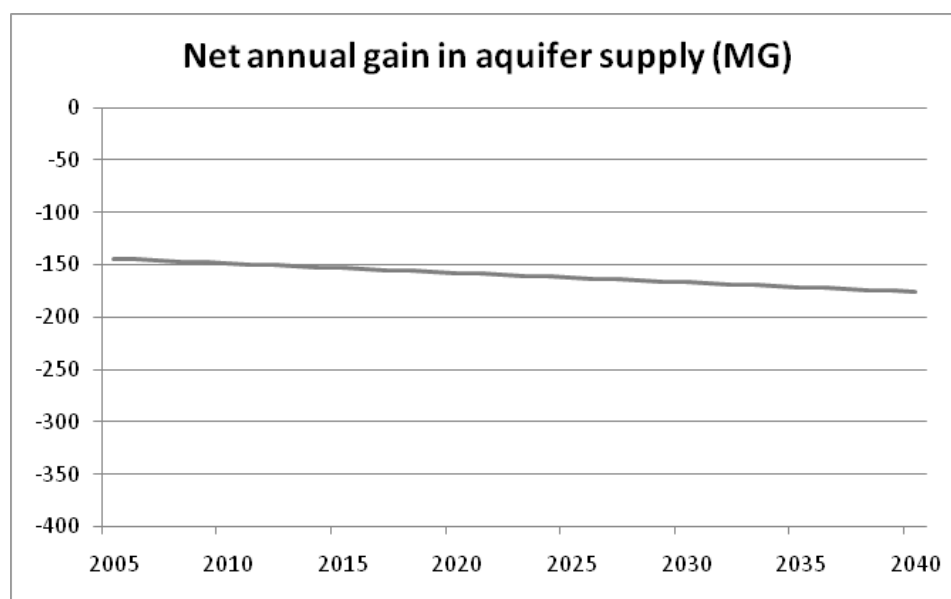


Figure 19. Scenario 1 results (Fort Campbell).

### Scenario 2 — Increased demand

Scenario 2 explores the possibility of demand increases beyond what is currently projected, both at Fort Campbell and in the region. For this scenario, increased regional water use is expected to be 125 percent of the previously assumed water use increase — this leads to a 20 percent increase in water use by the region over the coming 30 years instead of a 16 percent increase. Such a departure from the expected future water use could be due to population growth or significantly increased industrial use at the regional scale. It is assumed that an unexpected change in mission or a population increase on the installation may cause the amount of water use to stay stable over the coming 30 years despite water use reductions in compliance with E.O. 13514. Supply variables are assumed to continue following current patterns: precipitation patterns are assumed to stay the same and only a slight decrease, 2 percent, in aquifer recharge is assumed. Figure 20 shows the results of Scenario 2.

### Scenario 3 — Status quo

Scenario 3 assumes a continuation of the status quo: current population projections and consumption rates, and current precipitation patterns. It assumes a slight decrease, 2 percent, in aquifer recharge, but assumes the baseline values for changes in Fort Campbell and other groundwater withdrawals in the region. Figure 21 shows the results of Scenario 3.

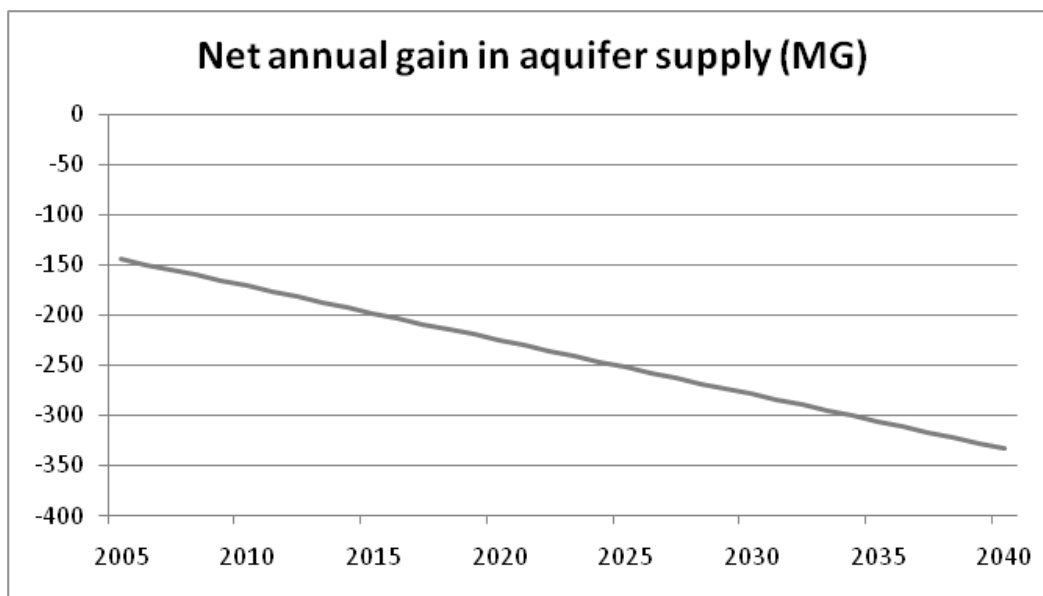


Figure 20. Scenario 2 results (Fort Campbell).

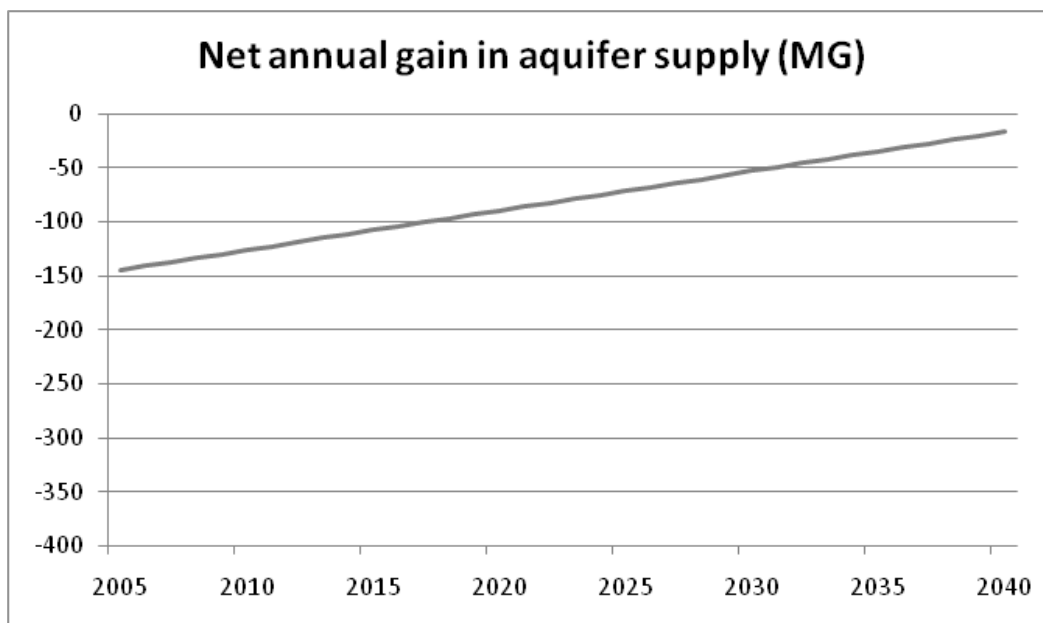


Figure 21. Scenario 3 results (Fort Campbell).

#### Scenario 4 – Water efficiency

Scenario 4 assumes that a regional level water conservation and efficiency program significantly reduces regional water consumption. Strategic intervention initiatives used in this scenario are a Public System Loss Management Program initiated in 2011, a Commercial/Industrial Water Conservation Program initiated in 2013, a Residential Water Conservation

Program initiated in 2016, and an Agricultural Water Conservation Program initiated in 2019. Water reuse was not considered as an option for this analysis as that would require the development of a separate distribution system.

The Public System Water Loss Management Program consists of a 50 percent reduction in losses over 2-year phase-in through leak detection and remediation programs. The Industrial Program consists of about a 39 percent reduction in usage over 8 years with 90 percent market penetration through water conservation program. The greatest percentage of water savings could be realized in traditional heavy industries, which could cut its current water use by three-quarters by using recycled and reclaimed water for cooling and other processes. Other industries that could lower water use by large percentages include paper and pulp, commercial laundries, and schools.

The Residential Program expects 39 percent reduction in use in older homes from 2016-2024 with 90 percent market penetration. Even without improvements in technology, an almost 40 percent reduction in water use is estimated to be possible by replacing inefficient appliances and reducing leakage. In addition, a policy change requiring new homes to include ultra low flow toilets and showerheads is implemented in 2016 with 100 percent penetration since it is code. The Agricultural Program consists of a 50 percent reduction in usage over 10 years starting in 2019 based on irrigation efficiency improvement and reduction of usage.

These conservation programs result in a 22 percent decrease in water usage between now and 2040 at the regional level, instead of a 16 percent increase. Supply variables and installation demand are assumed to continue following current patterns. Figure 22 shows the results of Scenario 4.

#### **Scenario 5 — Slower than expected population growth**

Scenario 5 assumes the regional population will grow at a slower rate than is currently expected. The status quo scenario assumes that the population of Montgomery County will boom in 2020 after a period of steady growth. This scenario assumes that the county does not experience the anticipated population boom and rather grows at just a little more than the rate expected for 2010-2020: 1 percent growth compounded annually.

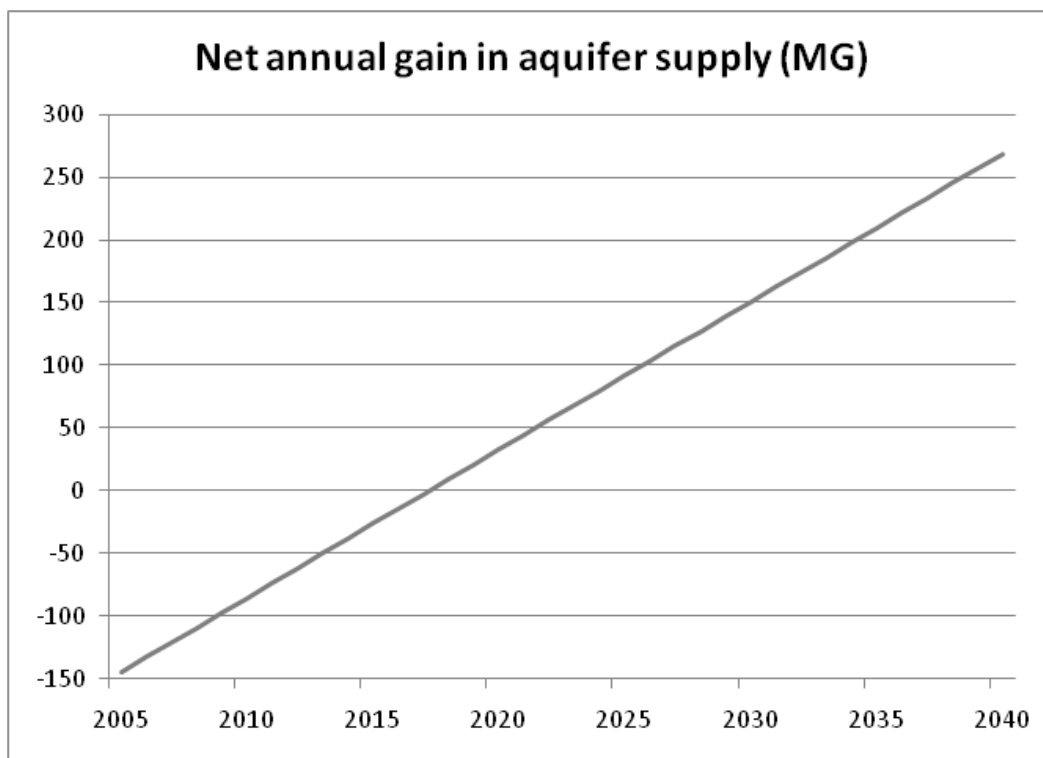


Figure 22. Scenario 4 results (Fort Campbell).

Christian County's annual growth rate is adjusted down by a quarter of 1 percent from that expected in the status quo scenario for each year. In this scenario, increases in population fail to offset the anticipated decrease in intensity of water usage (gpcd), resulting in actual increases in net annual aquifer supply. Overall, this scenario assumes that water usage by regional water users will decrease by 6 percent by 2040. Figure 23 shows the results from Scenario 5.

#### **Model results of the Fort Campbell regional supply model**

Since it is unknown how much water is available in the Mississippian aquifers in the Fort Campbell region, which give rise to Boiling Spring, the regional supply model examined the net annual gain in aquifer supply, in million gallons. This was calculated by subtracting estimated withdrawals from estimated annual recharge.

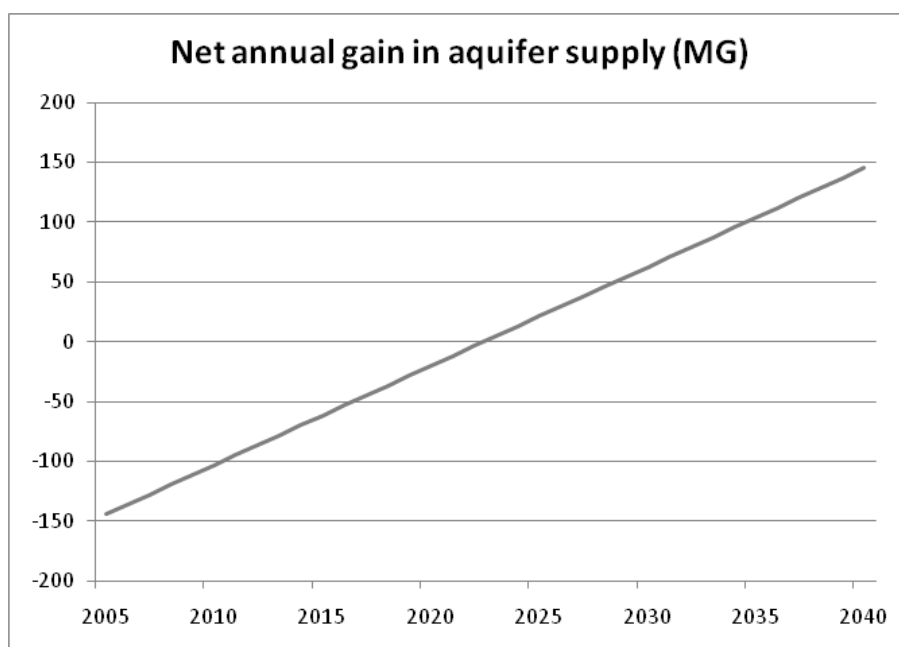


Figure 23. Scenario 5 results (Fort Campbell).

Table 10 lists the results of each scenario. Fort Campbell is currently experiencing a slight deficit in aquifer recharge of 0.4 MGD or just over 144 MG per year. Various scenarios predict both deficits and surpluses in net aquifer recharge for 2040, depending on the input variables. Aquifer recharge is expected to continue to be on the decline in both the extreme climate change scenario, and in the increased demand scenario, resulting in net annual deficits in aquifer recharge of 175 and 330 MG per year, respectively, by 2040. The status quo scenario predicts an increase in aquifer recharge over the coming 30 years, although not quite enough to result in an actual gain in aquifer recharge by 2040. The deficit that year is expected to be just over 16 MG.

Table 10. Fort Campbell region scenario summary (MGD).

	Baseline 2005	Scenario 1: Climate Change 2040	Scenario 2: Increased Demand 2040	Scenario 3: Status Quo 2040	Scenario 4: Water Efficiency 2040	Scenario 5: Decreased Pop. Growth 2040
Aquifer recharge	5.44	4.90	5.34	5.34	5.34	5.34
Groundwater withdrawals by Fort Campbell	3.79	3.01	3.79	3.01	3.01	3.01
Groundwater withdrawals by rest of region	2.05	2.38	2.46	2.38	1.59	1.93
Net gain in aquifer supply	-0.40	-0.48	-0.91	-0.05	0.74	0.40

Finally, both the water efficiency and decreased population growth scenarios predict increases in aquifer recharge, which yield net surpluses in aquifer recharge by 2040.

The actual rate of population growth for the region will play a large role in determining whether or not the region continues to experience yearly deficits in aquifer recharge. At the expected rates of growth, regional water consumption is expected to increase. At lower growth rates, however, even with population increases, regional water usage will decrease. Of course, whether or not the expected decreases in per capita water usage materialize is also important. These decreases are in line with current patterns of decreasing per Capita water use throughout the United States, but that does not mean they will occur on their own (Pacific Institute 2009).

The variability in these results, increasing versus decreasing water use, water deficits versus water surpluses, may result in a net regional gain or a net loss in aquifer recharge. Thus, with relatively little effort on the part of regional water users, it is possible to achieve annual net zero or even net gains in aquifer recharge by 2040. Water efficiency measures undertaken by Fort Campbell are key to ensuring this outcome, but they will not be enough in the face of either population growth or climate change. In either of these situations, the entire region will have to implement some water efficiency measures to achieve a sustainable water supply. These measures do not have to be as extensive as the off-the-shelf water efficiency program suggested in scenario 4, but they would have to go beyond the status quo. Taking steps to decrease average daily per capita water use, especially in Montgomery County where both per capita use and population are higher, could yield significant water savings. Sustainable groundwater use is fully achievable for this region by 2040.

### **Water sustainability assessment for the Fort Campbell region**

Determining whether the Mississippian aquifers from which Fort Campbell draws its water are being used sustainably is possible, but determining whether or not the region may face future water scarcity will always be unclear. Even if the net annual change in aquifer recharge continues to decrease into the future, the amount of water in the aquifer is unknown, and thus the seriousness of any particular deficit impossible to tell. There is a need for more research on regional groundwater resources. There has

been some research on groundwater flow, but it has been mostly to determine the potential for groundwater contamination, not to ascertain the amount of water available for withdrawal. Without an accurate picture of the available supply in the aquifer, an accurate picture of the water scarcity situation is impossible.

Nonetheless, the installation should undertake a serious effort to reach its water use reduction targets and work with regional water users and local governments to ensure that appropriate water efficiency measures are adopted regionally. The region is close to achieving a sustainable pumping rate. Water efficiency actions taken by the installation and the region should be able to achieve such a rate in the next 30 years.

Finally, while Fort Campbell relies solely on groundwater sources, and this study likewise focuses on regional groundwater supplies, it is important to monitor the regional surface water situation as well. The region is expected to see an increase in both the amount of rainfall and in the occurrence of droughts as the result of climate change. Without additional infrastructure to capture and store the projected increase in rainfall, these changes have the potential to stress the overall regional water supply situation during drought periods. Working toward decreases in the average daily per capita use will help the region to maintain adequate surface water supplies during a drought. The region as a whole should work to ensure appropriate measures are taken to safeguard future water supply that may be affected by climate change.

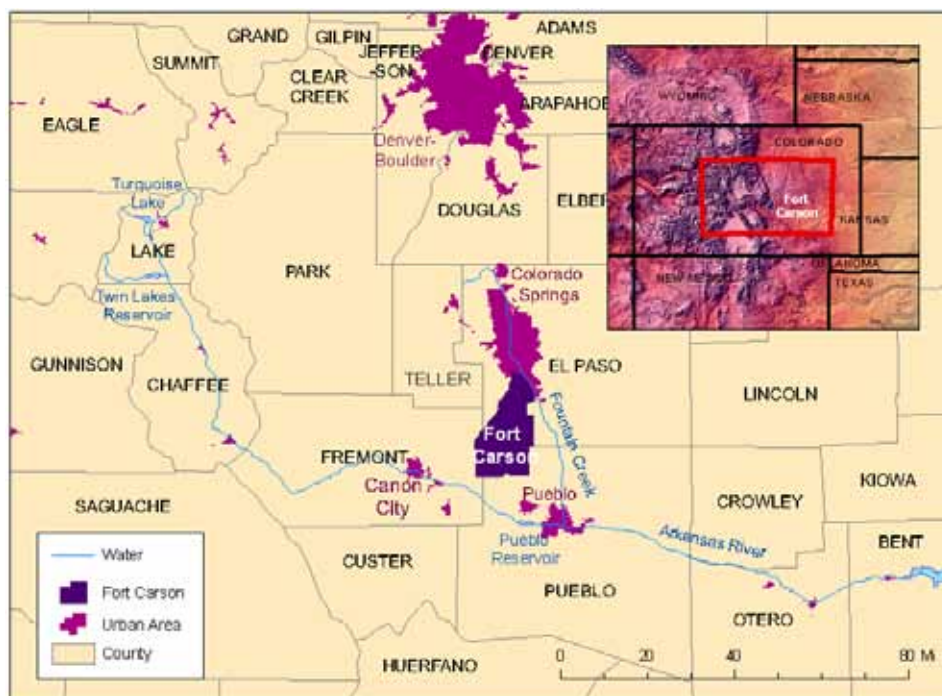
## 5 Fort Carson, CO

Fort Carson is a large Army installation located on the edge of the Rocky Mountains just south of Colorado Springs, CO (Figure 24). Fort Carson is a power projection platform and a Post Mobilization Maneuver Training Center. The installation is home to the 4<sup>th</sup> Infantry Division in addition to a number of other units and tenant organizations. By 2013, the ongoing Army transformations will result in an installation population of 25,000 military personnel stationed at Fort Carson, and 6500 civilian workers (contractors or DA civilians) (Fort Carson 2010).

### Regional characterization of Fort Carson

#### Demographic trends

The 2008 population of the seven-county Fort Carson region was estimated to be almost 860,000; however by 2040 the regional population is expected to grow to over 1.4 million people. This represents a regional growth of almost 64 percent over 32 years.



Source: National Atlas (2009)

Figure 24. Fort Carson, CO.



Table 11. Fort Carson region 2008 population and historical growth rates.

	2008 Estimated Population	2040 Projected Population	2008-2040 Growth
Chaffee	17,143	30,905	80.3%
Custer	4,123	9,176	122.6%
El Paso	597,249	974,404	63.1%
Fremont	48,034	75,558	57.3%
Lake	8,353	21,610	158.7%
Pueblo	157,389	251,296	59.7%
Teller	22,765	37,599	65.2%
Total	855,056	1,400,549	63.8%
Source: Colorado County Profile System (Colorado State Demography Office 2010)			

Table 11 lists individual county population estimates and projected growth. Population estimates for the years 2005 through 2008 were obtained from the Colorado State Demography Office. The projections are created using a cohort-component model and net migration (Colorado State Demography Office 2010). Population projections for the years 2036 through 2040 were estimated by assuming that the general trend in per county growth between 2000 and 2035 would continue out to 2040.

### Water sources

Fort Carson purchases water from the municipal water company, Colorado Springs Utilities (CSU). The utility derives its supply portfolio from a number of basins and sources that it developed in increments beginning in the 1870s. CSU's sources include 114,500 acre feet per year of developed water supplies —water rights that infrastructure currently enables them to use, and 46,500 acre feet per year of undeveloped water— water rights that CSU holds and addresses in specific future plans (Colorado Springs Utilities 2008). \* This “portfolio” includes primarily surface water, which the addition of the Southern Delivery System (SDS) — infrastructure that will allow the utility to tap into additional surface water supplies — will augment.

The US Bureau of Reclamation approved the SDS proposed plan after a detailed Environmental Impact Study (EIS), referenced frequently throughout this report, and a contentious public comment period. The

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\* Colorado Springs Utilities' 2008-2012 Conservation Plan (Colorado Springs Utilities 2010) also notes the existence of other water rights outside of these “developed” or “undeveloped” rights.

project entails the construction of a pipeline north from Pueblo Reservoir to deliver Fry-Ark Project water to project participants, including the City of Colorado Springs. The participants include several entities that currently own the water rights, but do not have the necessary infrastructure to use them. The pipeline would be built within the Arkansas River Basin.

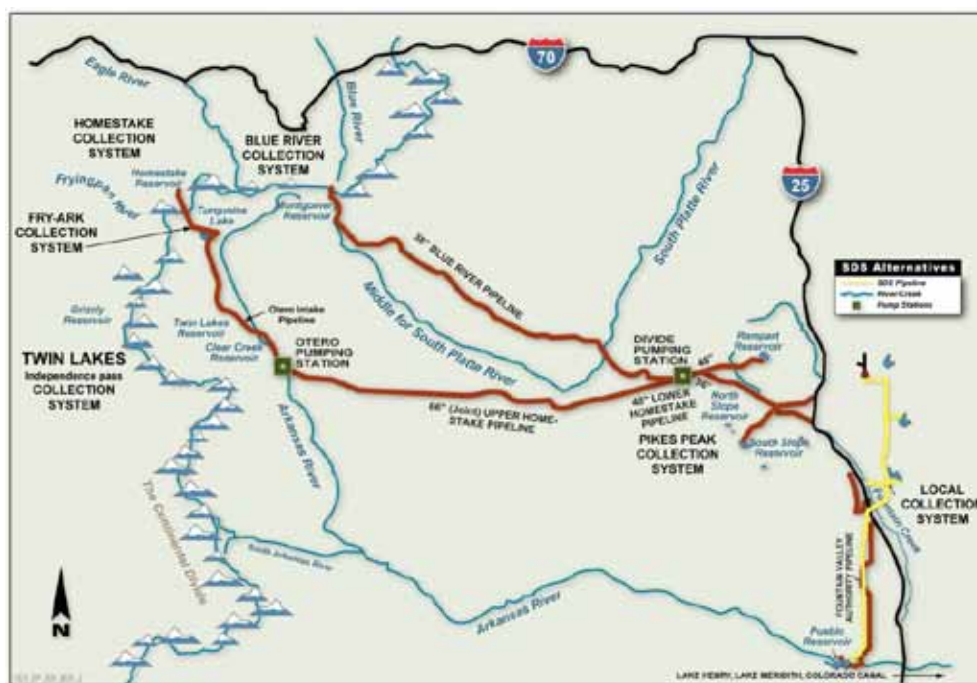
A number of other watercourses and supply systems are located in the study area (Figure 25). Those most relevant\* are:

- *Arkansas River.* At about 1450 miles long, the Arkansas River is the fourth longest river in the United States. Its river basin covers roughly 27 percent of Colorado's surface area, making it the state's largest. The river is fed by snowpack from the mountains around Leadville, Co.
- *Fountain Creek.* Fountain Creek is a tributary of the Arkansas River, with headwaters located on Pike's Peak and Rampart Range in the Colorado Springs vicinity. The city and surrounding communities are its primary users, who divert much of its tributary inflow.
- *Homestake Project.* This transmountain water diversion system pipes water from Homestake Creek to the Arkansas basin. The river is fed by snowpack from the Sawatch Mountains.
- *Fryingpan-Arkansas (Fry-Ark) Project.* The Fry-Ark Project is a transmountain diversion system that brings water from the Fryingpan River basin to the Arkansas basin. The ultimate destination for Fry-Ark water that is not diverted from flow is the Pueblo Reservoir. The average annual diversion is 52,000 acre feet. Ivanhoe Creek is a tributary to the Fryingpan that feeds the Busk-Ivanhoe system, a transmountain diversion to the Arkansas basin.
- *Twin Lakes Project.* This project is a transmountain diversion system that diverts from the Roaring Fork River to the Arkansas basin. On the Western Slope, the Roaring Fork drains to the Colorado River. The river is fed by snowpack from "the Sawatch, Collegiate and Elk ranges and eight 14,000 foot peaks" (US Bureau of Reclamation 2008).

Other water sources in the region include the Blue River system and the local Pike's Peak collection system.

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\* Descriptions summarized from the vast store of information in the Southern Delivery System Final Environmental Impact Study (US Bureau of Reclamation 2008).



Source: Colorado Springs Utilities/City of Colorado Springs (2010)

Figure 25. Water sources in the greater Fort Carson Region.

### Colorado water law\*

The Arkansas River Compact mediates the use of the river between the states of Colorado and Kansas, which have been in litigation over the agreement since the early 1990s. Recent court decisions have meant to bring Colorado into compliance by limiting the amount of well pumping in the lower Arkansas River Basin. The Western Slope waters are part of the Colorado River Compact.

Water law in Colorado is governed by a complex system of water rights within a prior appropriation system, which operates according to “first in time, first in right.” Users must hold a legal right to put to “beneficial use” a certain amount of water in a given surface water system. When enough water is not available to fulfill all existing water rights claims, those users “with earlier water rights (or senior water rights) have the priority of use ... over those with later rights (or junior water rights)” (US Bureau of Reclamation 2008). Ultimately, the State Engineer’s office in the Division of

\* The “Colorado Water Law” section paraphrases key points drawn almost exclusively from the cogent summary in US Bureau of Reclamation (2008), Appendix A.

Water Resources, Department of Natural Resources, administers these rights. Water courts adjudicate between different rights holders.

Scenario 5 (see below) mentions requests in the study area for additional storage rights for the Southern Delivery System development. Storage allows water to be retained for later use, as opposed to direct flow rights, which require immediate use of the water.

“Water rights may be purchased, sold, leased, rented, and transferred between parties subject to their decrees and the laws of the state” (US Bureau of Reclamation 2008). Although they are private property rights, they do not guarantee that the total amount decreed will be available. “Many river basins within the state, including the Arkansas River, are considered to be overappropriated” (US Bureau of Reclamation 2008). When all adjudicated water rights cannot be met fully, water use is limited to senior water rights under a “priority call.” “The ‘calling’ water right is the water right that is only being partially met; all junior water rights are shut off and all senior water rights are met” (US Bureau of Reclamation 2008). In drought times, it is possible that even senior rights may not be met.

## **Climate**

Fort Carson and the surrounding region enjoy a mild climate due to the protection from harsh weather provided by the Rocky Mountains to the west and the warm westerly winds, which prevent excessive cold during the winter. January lows for the region average about 14.5°F and July highs, 84.4°F. Smith and Hill report that average daily temperatures in the Arkansas River basin range from 46°F in the upper river valley to 55°F in the lower basin (US Bureau of Reclamation 2008).

Historically, the region has received an average of 17.4 in. of rainfall annually. Abbott notes that this can vary “from less than 10 in. on the valley floor to more than 40 in. at the crest of the mountains” (US Bureau of Reclamation 2008). The area does experience a large number of thunderstorms, which develop in the mountain ranges on almost any day with sufficient humidity. Flooding can occur due to heavy, localized thunderstorms, and to a lesser degree, due to rapid or heavy snowmelt off of the mountains. Despite this, the majority of Colorado’s population lives in this

belt of comparatively mild climate at the eastern edge of the Rocky Mountains (Doesken, Pielke, and Bliss 2003, National Weather Service 2010).

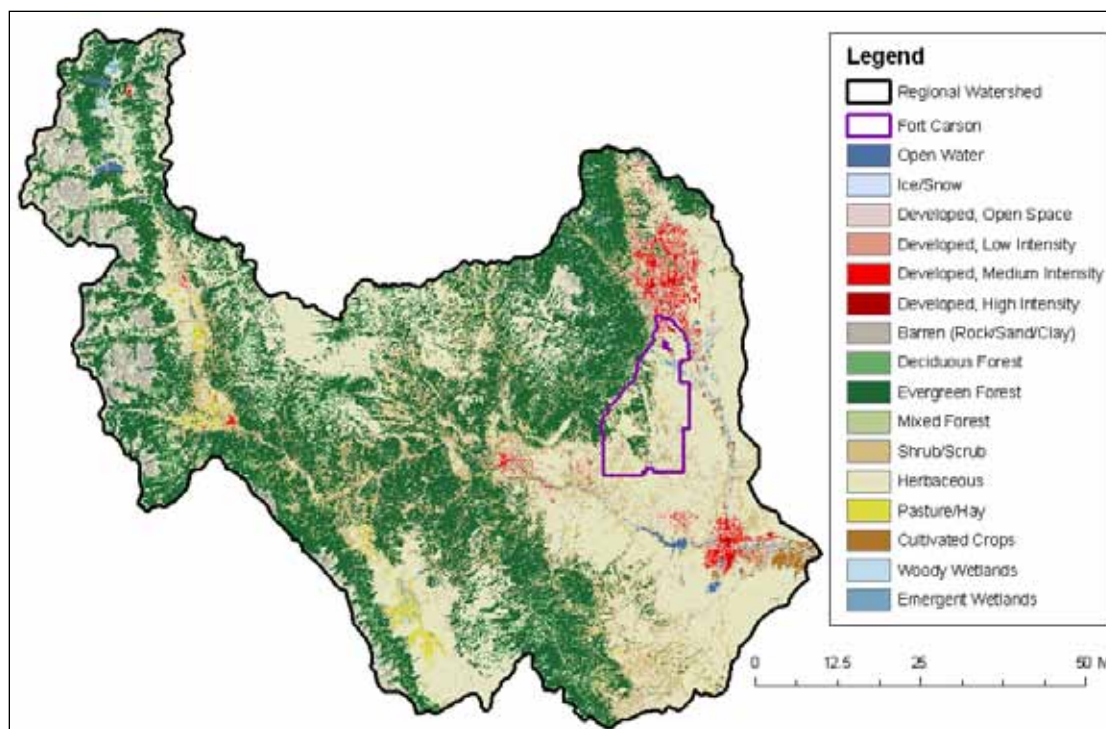
### **Topography**

Fort Carson itself is located at the western edge of the High Plains, which take up the eastern 40 percent of the state. Water flows down from the Rocky Mountains to feed the rivers that provide Fort Carson and the Colorado Springs area with their water supply. The western regional counties, at the headwaters of the river basin, extend past the foothills, into the mountains, and to the edge of the Continental Divide (Doesken, Pielke, and Bliss 2003, National Weather Service 2010). Fenneman divided the Arkansas basin into two distinct provinces east of Cañon City, one north of the 105 parallel and one south of it (US Bureau of Reclamation 2008). The mountainous western half is the upper basin, also called the Southern Rocky Mountains province. The lower basin, known as the Great Plains province, lies to the east. The US Forest Service marks the elevation range of the upper basin as between 5000 ft to over 14,000 ft. The eastern portion ranges from 3500 to 7500 (US Bureau of Reclamation 2008). Elevations on the western slope of the Rockies in this region are more similar to those in the upper basin than those in the lower.

### **Land cover**

Figure 26 shows land cover for the Fort Carson regional watershed. The majority of the watershed consists of undeveloped land, mostly forest and herbaceous plants, though there is some barren land in the higher elevations to the west of the region. Grasslands cover about 76 percent of the Arkansas River Basin, and forest, about 13 percent (US Bureau of Reclamation 2008).

According to the Colorado Water Conservation Board, the basin is about 1 percent developed, including urban and suburban use. Land use along the river corridor is mainly agricultural, and the rest is mostly range (US Bureau of Reclamation 2008). The three notable areas of developed land are Colorado Springs and the cantonment area of Fort Carson, in the northeast of the study region; Pueblo, in the southeast of the study region; and Cañon City, further to the west. Additionally, there seems to be a limited amount of pasture land within some of the hillier/more mountainous area.



Source: US Geological Survey, National Land Cover Dataset (2001).

Figure 26. Regional land cover.

### Historic water demand

As of 2005, the seven counties in the Fort Carson region withdrew 799 MGD; approximately 95 percent of this water or 757 MGD was surface water, though not all of it from within the regional watershed. This represents a 133 percent increase in overall water use for the region since 1985 and a 149 percent increase in surface water use. Table 12 lists water use in the region, broken down by county over time.\*

### Developing the Fort Carson regional model

This study analyzes existing data on water availability and use in the region and projects these trends out to 2040. A series of possible scenarios for water availability in 2040 was developed. These scenarios should help both Fort Carson and the surrounding region plan for adequate water supply in the coming decades.

\* Note that the exceptionally large amount of water used in 1990 seems to be associated with an abnormally high amount of water devoted to irrigation uses. This could be caused by either an unusually dry year, resulting in an increased need for irrigation, or a different method for calculating irrigation water use than was employed in other years.

Table 12. Fort Carson region historical water use (1985-2005).

	1985		1990		1995		2000		2005	
	Surface Water	Total Water	Surface Water	Total Water	Surface Water	Total Water	Surface Water	Total Water	Surface Water	Total Water
Chaffee	57.89	60.68	115.25	117.23	54.65	56.69	71.24	72.16	121.94	122.91
Custer	33.17	33.5	25.2	25.8	40.91	41.62	48.85	49.3	44.75	45.32
El Paso	82.04	108.82	90.64	125.07	111.48	134.7	121.61	138.49	129.82	157.08
Fremont	89.24	90.19	187.49	193.7	155.19	158.86	159.54	160.42	150.03	150.85
Lake	18.6	21.16	41.24	43.69	23.76	26.21	40.38	41.02	13.76	14.67
Pueblo	253.16	281.04	178.21	221.66	224.83	246.09	235.71	246.32	291.24	301.30
Teller	5.87	6.55	7.67	8.81	8.01	9.23	5.44	6.84	5.41	6.42
Total	588.84	601.94	645.7	735.96	618.83	673.4	682.77	714.55	756.95	798.55

Source: US Geological Survey (2005).

### Regional water supply model

The baseline for the Regional Supply Model of the Fort Carson study area represents major contributors to Colorado Springs Utilities water supply. The Regional Supply Model is broken down into water contributions from the Eastern Slope of the mountains — roughly the regional watershed identified in Figure 27 — and water contributions from the western slope of the mountains — west of Lake and Chaffee Counties.

Gages from three watercourses on the Western Slope of the Continental Divide represent input from the Homestake Creek, Roaring Fork River, and Ivanhoe Creek. The Final Environmental Impact Statement (FEIS) for the SDS notes the importance of these particular gages in capturing streamflow changes during the modeling effort for that project; therefore, these appear to be appropriate data points. For the years where water availability is forecast, runoff and change in county demand on the Rockies' Western Slope (where these flows originate,) can alter potential contribution to the Colorado Springs/Fort Carson area's water supply. The model provides for changes in both runoff and regional demand and consumptive use. Available water may be reduced from current levels if the amount of water used consumptively (i.e., used but not returned to the river through the wastewater system) from the Upper Colorado water-resources region increases. The baseline is set to the percentage of fresh-water withdrawals used consumptively in the region from 1995 USGS water-use data.

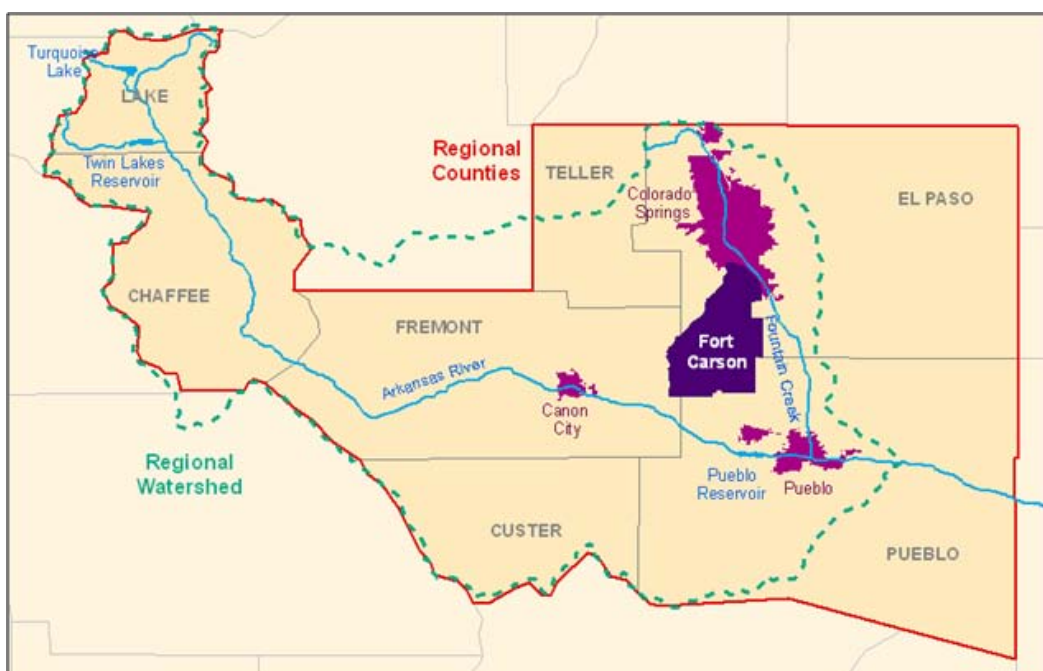


Figure 27. Regional demand model study region.

The two largest contributors to the study area's potential water supply on the eastern side of the Rockies, the Arkansas River and Fountain Creek, are represented in the lower segment of the Regional Supply Model. A second consumptive use factor uses the USGS percentage for the Arkansas-White-Red water resources region. The gages selected were also referenced in the SDS FEIS and are the closest to Pueblo Reservoir that are not influenced by dam releases. Runoff, demand within the study area, and the consumptive use percentage all can be modified. Demand estimates for users on this side of the Rockies come from the Regional Demand Model.

While the Wellsville gage on the Arkansas River is actually used for daily monitoring under the Upper Arkansas Voluntary Flow Management Program, it was not incorporated because a yearly average of this flow would have no added meaning in this context. The average would eliminate daily and seasonal variation, which are considerable. Flow may exceed the goal on some days and not others. Year-round daily flows of at least 250 cubic feet per second (cfs) must be maintained, with special attention to flows during Spring and Fall to protect fish spawning and hatching (US Bureau of Reclamation 2008). Limits are also placed on daily changes in flow, and Summer "augmentation" for recreation, which add flows of up to 700 cfs,



add variation. These flows were not met a small percentage of the time between 1990 and 2007, mostly during droughts in 2002 and 2003 (US Bureau of Reclamation 2008).

The Regional Supply Model shows projected potential contributions to water supply. The assumption is that flow represents water available for withdrawal, although only some of this water may be legally available based on existing water rights, thus the term “potential water supply.” The area may also have existing storage. The Regional Supply Model does not have a way to account for the complex water rights transfers and allocations that comprise water “portfolio” management in Colorado. It cannot represent actual water availability or scarcity to end users.

Therefore, the alteration of these flows in the scenarios below should be viewed as a useful method to understand the regional water supply factors and to test their sensitivity to possible actions and situations. While the SDS FEIS created complex water models, these models incorporated water rights and planning processes that were subject to public scrutiny. Decisions on the installation may be subject to different requirements, but the need to understand the limitations, but usefulness of the forecast water supply information, remains crucial.

#### **Regional water demand model**

The Regional Demand Model primarily uses data derived from the USGS data (2005), which detail in-stream water withdrawals at the county level. The study area consists of the seven counties, which by and large fall into the regional watershed, and which provide surface water supplies to regional users: Arkansas Headwaters, Upper Arkansas, and Fountain watersheds (Figure 27). Three counties — Teller, El Paso, and Pueblo — lie only partially within the regional watershed. Thus, it is unlikely that all the water withdrawn in those counties is from within the regional watershed.

For the sake of this analysis, it is assumed that the portion of water withdrawn from within the regional watershed — with the exception of water withdrawn for public supply in El Paso and Pueblo counties — is equivalent to the percentage of the county that falls within the regional watershed. Therefore water withdrawals from the USGS data were weighted by within-watershed county area.

Public supply withdrawals within El Paso and Pueblo counties will not be weighted as Colorado Springs and Pueblo — the main population centers in those counties are entirely within the watershed and are the major population centers *for* the watershed. Table 13 lists the amount of water withdrawn for a variety of use types for each county in 2005, and the amount of water assumed to be withdrawn from within the watershed, that is, the “basin.”

After 2005, withdrawals are forecast using the population data obtained from the Colorado State Demography Office. Water use projections vary with population and how they use water. Public supply and domestic water use are expected to increase with population growth whereas water use for irrigation, livestock, and aquaculture is expected to decrease with population growth under the assumption that rising municipal populations and growing urbanization will continue the national trend of farmland conversion for development. Industrial self-supplied water and water use for mining is not affected by population growth. For each year, all categories are summed, and counties are also summed for a regional total.

Table 14 lists the results of the Regional Demand Model. Most of the counties within the region are actually expected to experience water demand decreases, due to decreases in water usage for irrigation as agriculture is displaced by residential development. Nonetheless, the increases in water demand in Colorado Springs and Pueblo are projected to overwhelm these decreases. Between 2005 and 2040, within-watershed regional demand is projected to grow by 8.3 percent, from roughly 655 MGD to almost 710 MGD.

Table 13. 2005 region baseline water usage data.

	Public Supply	Domestic	Mining	Industrial	Irrigation	Aquaculture	Live-stock	Thermo- electric	Groundwater	Surface Water	Total	% in Basin*	Basin Withdrawal
Chaffee	1.7	0.3	0.1	0.0	103.6	17.2	0.1	0.0	1.0	121.9	122.9	100.00%	122.91
Custer	0.1	0.3	0.0	0.0	44.8	0.0	0.1	0.0	0.6	44.8	45.3	100.00%	45.32
El Paso	116.7	3.3	0.1	0.0	34.2	0.0	0.4	2.5	27.3	129.8	157.1	38.98%	132.41
Fremont	7.6	0.4	0.1	0.5	126.6	0.0	0.2	15.5	0.8	150.0	150.9	100.00%	150.85
Lake	1.1	0.3	0.2	0.1	12.7	0.3	0.0	0.0	0.9	13.8	14.7	100.00%	14.67
Pueblo	83.9	0.6	0.1	72.3	124.7	0.4	0.4	18.9	10.1	291.2	301.3	46.26%	184.48
Teller	1.3	0.2	0.0	1.2	3.7	0.0	0.0	0.0	1.0	5.4	6.4	58.35%	3.75
Total	212.4	5.2	0.6	74.2	450.3	17.9	1.1	36.9	41.6	756.95	798.55		538.10
* Except with regard to public supply use in El Paso and Pueblo Counties, both of which are unweighted. Unit is millions of gallons a day. Source: US Geological Survey (2005).													

Table 14. Fort Carson regional demand model results (MGD).

	2005	2010	2015	2020	2025	2030	2035	2040
Chaffee	122.9	120.8	114.8	106.9	101.6	98.1	95.8	92.7
Custer	45.3	43.5	40.0	37.0	34.6	32.8	31.3	30.4
El Paso	133.6	144.6	154.4	166.9	179.6	192.5	205.3	215.4
Fremont	150.8	149.3	144.8	140.1	136.2	133.0	130.4	129.0
Lake	14.7	14.0	13.2	12.6	12.2	12.0	11.9	11.9
Pueblo	184.0	188.3	193.1	199.9	206.7	214.0	221.8	226.5
Teller	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.8
Total	655.1	664.3	664.1	667.1	674.6	686.1	700.2	709.5

These demand forecasts feed the Regional Supply Model's "study area demand" input. Weights are used when only part of a county falls within the regional watershed. For example, only part of the each county may lie within the portion of the watershed draining to the Arkansas River versus the portion of the watershed draining to Fountain Creek. Demand could be further apportioned between these two sub-watersheds. Instead, this model aggregates the flows from both watersheds for simplicity to capture public supply withdrawals within the study watersheds that may be used in other basins. The following sections discuss the results of the Regional Demand Model used in each of the proposed scenarios.

#### **Fort Carson installation demand model**

The following sections explain the detailed assumptions and inputs of the Installation Demand Model, which uses Fort Carson real property data and average water use by structure type to forecast future consumption.

Table 15 lists the inputs used to estimate baseline water use for Fort Carson. The baseline water use in the Installation Demand Model was constructed from a combination of the most recent data available, primarily 2008 data with some from 2009. "Barracks Units" is roughly equivalent to the single soldiers Fort Carson can house in its enlisted personnel housing and "Housing Units" to the number of families. Both of these values come from real property data contained in the Headquarters Installation Information System (HQIIS) (ACSIM 2009). "Military Stationed," "Transient Population," "Dependents," and "Civilian Workforce" come from the Army Stationing and Installation Plan (ASIP).

**Table 15. Fort Carson installation water demand model baseline inputs.**

	Baseline (2008/2009)
Barracks Units	9,651
Housing Units	2,661
Military Stationed	17,932
Transient Population	246
Dependents	8,679
Civilian Workforce	5,357
Typical Military Family Size	2.01
Deployment Factor: Family Housing	0.80
Deployment Factor: Barracks	0.65
Industrial/Maintenance Factor	1.00
Storage Growth Factor	1.00
High Water Use Facilities Factor	1.00
Irrigated Land Factor	1.00
ET (Moisture Deficit)	62.98
Losses Factor	0.10

The ASIP and housing numbers are forecast out as far as they have been cited in Fort Carson plans and ASIP, but could be forecast further with additional information.

“Deployment Factor” is an estimate representing the average occupancy level of existing housing on-installation. Vacancy can be due to troop deployment or training movement. A factor of 0.80 means that on average, 80 percent of the housing is occupied (20 percent is vacant) over a given year.

The growth factors below (“Industrial/Maintenance” through “Irrigated Land”) are all set to the default of 1.00. Installation planners and staff who know the master plan can adjust these by percentage (i.e., 1.25 in a given year for Storage means that, for this type of facility, 25 percent more buildings will exist than in previous years). This will affect overall water use and can be adjusted with as much detail at the annual level as desired. In particular, the high water use factor may need to be adjusted upward in the future due to additional shower and toilet units, which are expected to be added for motor pools and brigade buildings in the near future.

“ET” is a “moisture deficit” factor that represents region-specific evapotranspiration. Here, this is 62.98, an estimate of evaporation from Pueblo Reservoir using 1975-2002 meteorological data (Oregon Climate Service 2009).

“Losses” factor represents percentage of water lost in transit through pipe leaks. Fort Carson is estimated to lose 10 percent of its water to leaks. This estimate is based on rules of thumb for water loss in public water systems in the United States.

Table 16. Baseline water consumption by unit.

Consumption (gpud)	Baseline
Family Housing	87
Barracks	87
Dependent Schools	5.8
Medical	1,236
Industrial/Maintenance	700
Lodging	150
Admin/Moderate Users	1,204
Community and Commercial: Non-food relate	629
Community and Commercial: Food-related	906
Storage	10
High Water Use Facilities	621

Table 16 lists baseline consumption numbers in gallons per unit per day (gpud) by type of real estate. In most cases, the unit is the building, although in some cases, the unit is per capita (family housing, barracks). The 87 gallons per capita per day water use estimate for housing and barracks is based on reported numbers for average per capita residential water use in nearby Denver (Walton 2010). Other factors are calculated from building-level metered data, if possible, or are rules of thumb derived from Billings and Jones (2008). These assumptions are a source of error. Efforts to create water factors based on metered data for each of the different building categories would improve model accuracy. “High water use facilities” are based on a general rule of thumb because the types of buildings in this category are so varied.

Altogether, this resulted in a baseline annual average use estimate of 2.68 MGD. This estimate is slightly higher than Fort Carson’s reported water use for the 2008 baseline year of 2.08 MGD.

#### *Notes on potential cost*

The Installation Demand Model also contains a “Costs” spreadsheet. It uses Fort Carson’s 2009 water rates derived from billing data that DPW provided. The cost used for Rate A is \$2.1782 per 1,000 gallons; the cost under Rate B is \$2.8752 per 1,000 gallons. Rate C is a hypothetical rate at double the cost of Rate A, because Colorado Spring Utilities says that rates will double approximately by 2016 to pay for the multi-billion dollar Southern Delivery System and other system upkeep. This rate increase may not be applicable to military installations because it is quoted from a business rate information fact sheet (Colorado Springs Utilities 2010).

DPW personnel mentioned other water rate details that are included here for information. Fort Carson sends 10 to 20 percent of its treated effluent

to water the golf course. Colorado Springs Utilities (CSU) charges the installation for not returning this water to its system. Fort Carson is said to have a military, seasonal, declining block rate as follows: November through April - \$0.0162/cf and May through October - \$0.0305/cf (Guthrie 2010). In general, Fort Carson pays for maximum daily and yearly capacities.

Figure 28 displays the results of the installation demand model for Fort Carson. The “baseline annual average” represents projected water demand for the installation if water usage were to continue following current trends. “Annual MGD w/efficiency” represents the projected water demand for the installation should water efficiency measures be used in compliance with E.O. 13514.

High water use does not include one building type (Category Code 73075, SEP TOIL/SHOWER) that could not be identified with certainty. Lacking more information, this type of building was not included in the forecast. If these can be identified, the forecast needs to be adjusted upward.

*Installation demand model results*

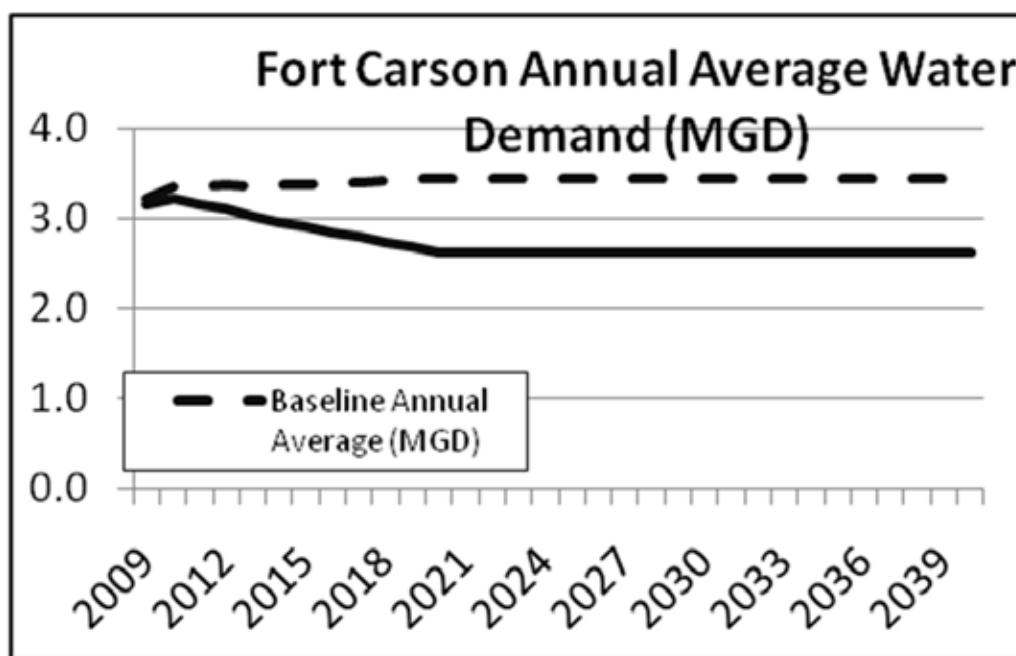


Figure 28. Fort Carson demand model results.

Contacts on the installation also mentioned at least one outdoor swimming pool that is not in the installation's real property data. This would also elevate the total, although perhaps not enough to make a significant difference (Guthrie 2010).

## **Fort Carson 2040 water availability scenarios**

The objective of this study was to project water availability 30 years into the future. Therefore the baseline water supply and demand were projected to the year 2040. The potential for water scarcity was estimated using several different scenarios and different assumptions.

### **Scenario 1 – High-emissions climate change**

Scenario 1 presents a potential future for the region in which climate change effects to water supply are similar to those predicted in various high greenhouse gas scenarios developed by climate modelers. Primarily, this means lower runoff into water supply streams. For the Western Slope streams, which are part of the larger Colorado River Basin, runoff is reduced by 25 percent from current levels; runoff on the west side of the Rockies is assigned to each stream in proportion to the amount of water the stream contributes to the total Western Slope flow. For the Eastern Slope streams, which are part of the Arkansas River Basin, runoff is reduced by 10 percent. Both of these reductions are at the extreme end of expected reductions for each river basin (Lettenmeir et al. 2008).

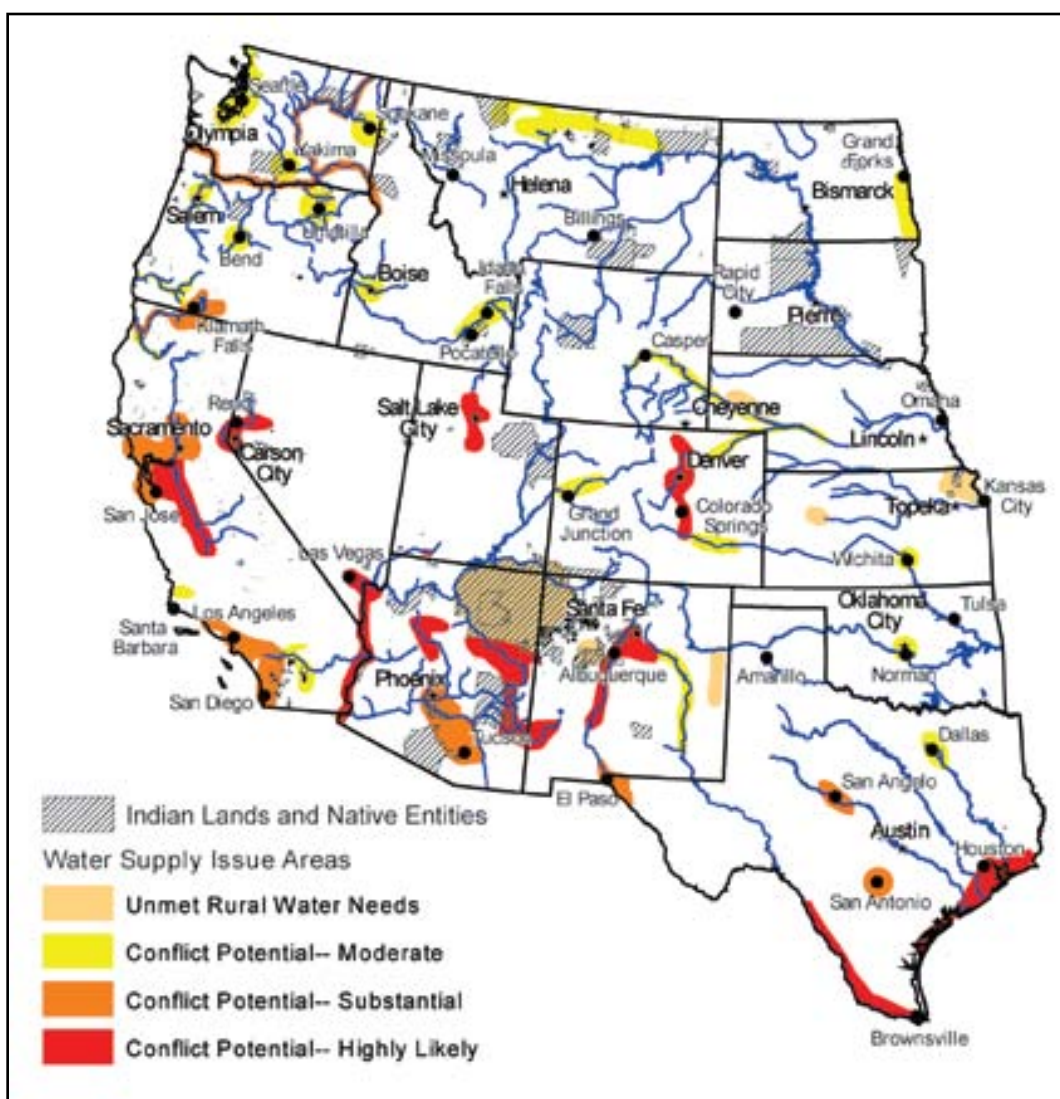
Other water supply variables are set to the baseline values. Although consumptive use is often expected to increase with reduced water availability, the reduced runoff will be significant. Thus, the scenario assumes that the region will take steps to mitigate the reduced runoff through watering restrictions. Therefore, consumptive use holds steady at the baseline. Change in county demand in the study area is taken from the baseline Regional Demand Model.

Demand on the Western Slope is not part of the regional demand projections, but sources are available that quantify future needs compared to current years. The Northwest Colorado Council of Governments (2003) projects that demand from this area will increase by 130 MGD in coming years. This increase in demand is included in the regional supply model. The effect is that Western Slope water contributions will drop to zero by 2024. This increase in Water Demand from the Western Slope is applied in all five water supply scenarios.



While this result is unlikely and does not account for water management and projects underway, it does highlight the increased potential for conflict over water in the Colorado River Basin in the future, conflict potential that extends down the river into other ecosystems and communities that would also draw on that water for life and livelihood in the United States and in Mexico (Figure 29).

The Colorado is a river under siege. Except for unusually high flood years, virtually the entire flow of the Colorado is diverted and used before reaching the river's mouth at the Upper Gulf of California (Sea of Cortez). This has decimated its once-extensive delta and turned the mighty river into a trickle. Even in this degraded state, the remaining delta still comprises the largest and most critical desert wetland in North America. (Pacific Institute 2009)



Source: US Global Change Research Program (2009).

Figure 29. Potential future water supply conflicts.

## **Scenario 2 — Slower decreases to agricultural demand**

Scenario 2 is based on the possibility that agricultural water use falls at a slower rate than is currently projected. This could occur if incoming regional growth is more concentrated than is currently expected and less agricultural lands are converted to residential or other uses. In the baseline water demand model, agricultural water use is projected to decline at a rate that is half the expected population growth rate for the region. For each 1 percent increase in population growth expected, a half-a-percent decrease in agricultural water use is expected; in the altered regional water demand projection for this scenario, agricultural water use is projected to drop only one quarter of 1 percent for each 1 percent increase in regional population. This alteration results in a 2040 regional water demand of 752.6 MGD instead of 709.5 MGD.

Water use from the Western Slope is expected to increase by 130 MGD, as it did in the previous scenario. On the supply side, runoff is reduced at the low-emissions end of the climate change scenarios — 10 percent for runoff in the Colorado River Basin (Western Slope) and 5 percent for runoff in the Arkansas River Basin (Eastern Slope). These runoff reductions are used for Scenarios 3 through 5 as well. Consumptive use from the river basins likewise remains at baseline levels.

## **Scenario 3 — Status quo**

Scenario 3, the status quo scenario, is the simplest of all the scenarios. It explores the possibility of current trends continuing on their projected path with little to no change. Consumptive use and the Regional Demand Model are assumed to vary as expected — that is, at the baseline. Western Slope demand is again expected to increase by 130 MGD. Finally, runoff reductions are set equivalent to those of the low-emissions end of climate modeling discussed in the previous scenario.

## **Scenario 4 — Regional water efficiency**

Scenario 4 explores the possibility of the region as a whole banding together to achieve significant water use efficiencies in the wake of the water shortages anticipated for the larger Colorado River Basin. Water use experts believe that up to 40 percent water savings are already achievable in many regions using off-the-shelf technologies such as low-flow fixtures and changes in landscaping and irrigation (Gleick et al. 2003, Cooley, Christian-Smith, and Gleick 2009). This scenario proposes a less ambi-

tious regional water-savings goal of 25 percent — roughly on par with the water savings currently being pursued by Fort Carson in accordance with E.O. 13514. Thus 2040 water demand from within the region is assumed to be 25 percent below the current-expected 2040 water demand: 532.2 MGD. Not only is this figure below the baseline projected water demand, it is actually below the current regional water demand.

Other factors — consumptive use, water demand from the Western Slope, and runoff — remain the same as in the previous scenario. Consumptive use remains at the baseline, water demand from the Western Slope is expected to increase by 130 MGD, and runoff reductions are expected to be only moderate.

#### **Scenario 5 — Added southern delivery system storage**

This scenario incorporates the additional service that is likely to be provided to the area as a part of the SDS. It is important to note that the demand projections used in this scenario are those developed for this study and not those from the forecast in the SDS EIS. Furthermore, the Sierra Club leveled criticism at the SDS EIS, contending that the forecasts in that document did not take into account demand increases caused by potential growth enabled by the SDS, rather only non-SDS influenced demand increases (US Bureau of Reclamation 2008). The relationship between growth and infrastructure seems to be a positive feedback loop - infrastructure responds to growth caused by many factors, but infrastructure existence is also one factor that may encourage growth. For instance, some municipalities tie new exurban subdivision approval to capital expenditure planning by making it contingent on the existence of infrastructure service capacity.

Each participant in the SDS — all of whom are located within the study region — is individually requesting a long-term excess capacity storage contract from the Bureau of Reclamation. Together, the four participants have requested a total amount of annual storage equivalent to 37.5 MGD. While these storage rights are not the same thing as direct flow rights, this model is based on direct flow. The storage is therefore treated as direct flow here to provide a general picture of the effect of the additional storage rights on the overall water supply system. Thus, all of these additional storage amounts are assumed fulfilled and added to the contributors to Pueblo Reservoir, under the understanding that this is not an indicator of actual availability for Fort Carson or Colorado Springs.

Other variables in the model are all set equivalent to their values in the status quo scenario: regional water demand and consumptive use are set at the baseline, Western Slope water demand is expected to increase by 130 MGD, and runoff reductions are moderate.

### Scenario results

Table 17 lists the results for each scenario developed for the Fort Carson Regional Model. The following paragraphs detail assumptions made in each of the scenarios and discuss the results.

## Water sustainability assessment for the Fort Carson region

All scenarios show zero contributions to the Fort Carson region water supply from the Western Slope. This is a result of holding the future demand increase called for by other Western Slope users at the level called for by the Northwest Colorado Council of Governments report. It is assumed that all the supply that Western Slope users require comes from sources that would otherwise feed the gages used in the Regional Supply Model. This is a highly unlikely situation in reality, but serves to introduce some conclusions of this modeling effort.

First, this model cannot capture the complex workings of the water rights system in Colorado. If it could, the case would likely be that water provided to study area users through trans-mountain diversions would be senior to the new storage requests by the Western Slope users, and supply would not be curtailed. This gives rise to a broader observation about water rights. If not for this system of rights, the development pattern in Colorado as it now exists would not be possible, and the nature of water resource management would be entirely different. The water rights system is exceedingly complex to the point that water planners talk in terms of water “portfolios,” which conjures imagery of the complicated trades and market monitoring of a large securities firm.

Table 17. Scenario results — Fort Carson regional model.

	2005 Baseline	Scenario 1: High- emissions climate change - 2040	Scenario 2: Slower decreases to ag. demand - 2040	Scenario 3: Status Quo - 2040	Scenario 4: Regional water efficiency - 2040	Scenario 5: Added SDS storage - 2040
Western Slope Contributions	48.64	0.00	0.00	0.00	0.00	0.00
Eastern Slope Contributions	321.06	278.54	269.04	286.42	373.53	323.92
Total Water Contributions	369.71	278.54	269.04	286.42	373.53	323.92

To fulfill water demand through this private property system, elaborate mechanisms have developed (e.g., the Southern Delivery System), which are sometimes rife with contention and consequences downstream. It is a best management practice to encourage water resources staff at Fort Carson to allocate time for engagement in such regional planning processes, because the installation is part of the region and shares the resource.

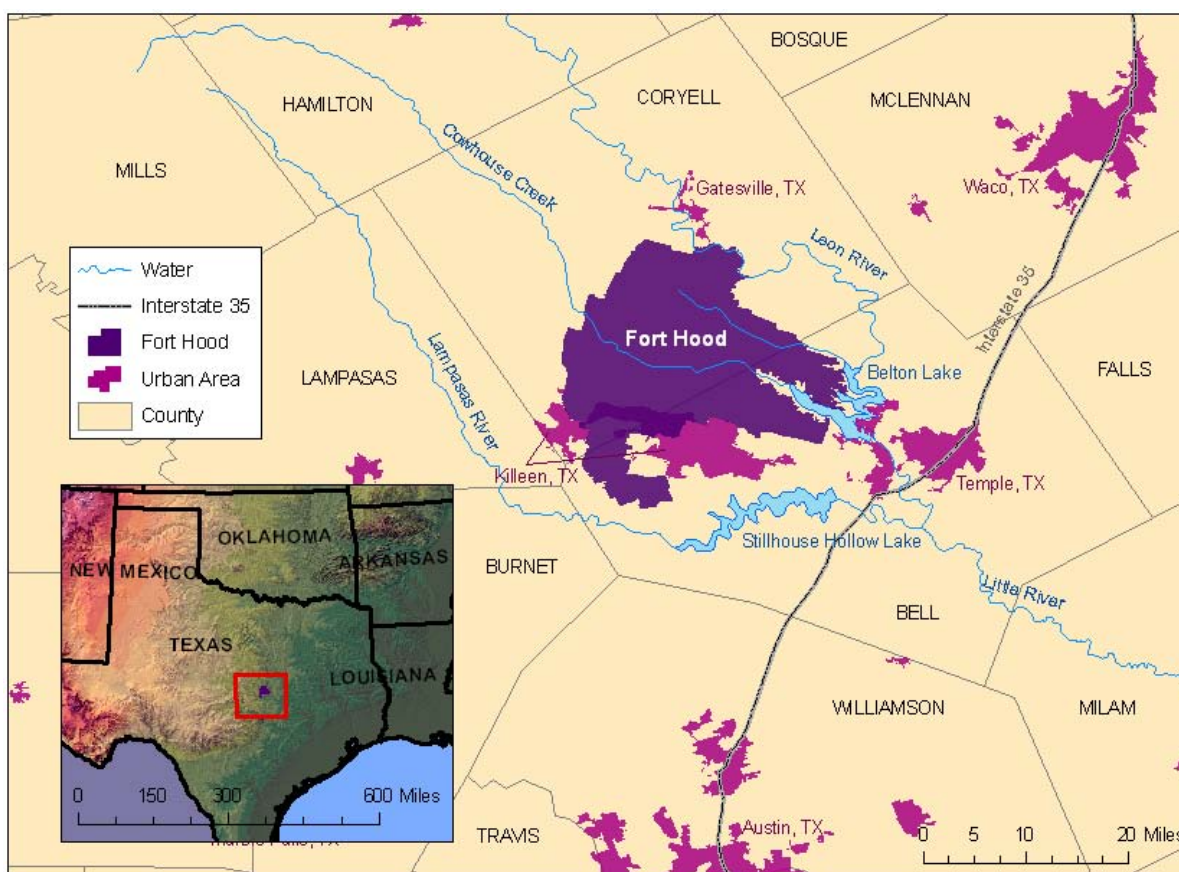
Finally, Fort Carson can continue to be a leader in the Army and the region in water efficiency innovation if Fort Carson personnel continue to implement water saving plans and practices. These include the Central Vehicle Wash Rack, an array of interior fixture and appliance retrofits, water policy/restrictions, water conserving landscape practices, replacing once through cooling systems, distribution system improvements, seasonal water rates for reimbursable customers, and wastewater reclamation (Guthrie 2010).

Some buildings are metered, such as the sports complex. As metering increases, the Installation Demand Model or other tools should be updated with more accurate information to help visualize potential water use reductions. Even temporary metering of select buildings from each category could improve accuracy.

Efforts should be made to facilitate the funding and inclusion of water efficiency measures in the building design process and in updates to contracting standards. Fort Carson achieved a 30 percent reduction in water use in recent years and new goals should help further that achievement.

## 6 Fort Hood, Texas

Fort Hood is the largest active duty armor post in the United States spanning over 340 square miles in central Texas. The installation has a community of over 297,000 soldiers, family members, and retirees. Fort Hood is located 60 mi north of Austin, 50 mi south of Waco and 160 mi south of Dallas/Fort Worth (Figure 30) Fort Hood serves as a major training base for the US Army. It is also a mobilization center for Army Reserve and National Guard units. The Fort is home to the 1<sup>st</sup> Cavalry Division, the 1<sup>st</sup> Army Division West and Headquarters Command III Corps, and a number of other units and tenant organizations (Fort Hood Public Affairs Office 2009a, 2009b; Fort Hood 2010).



Source: National Atlas (2009).

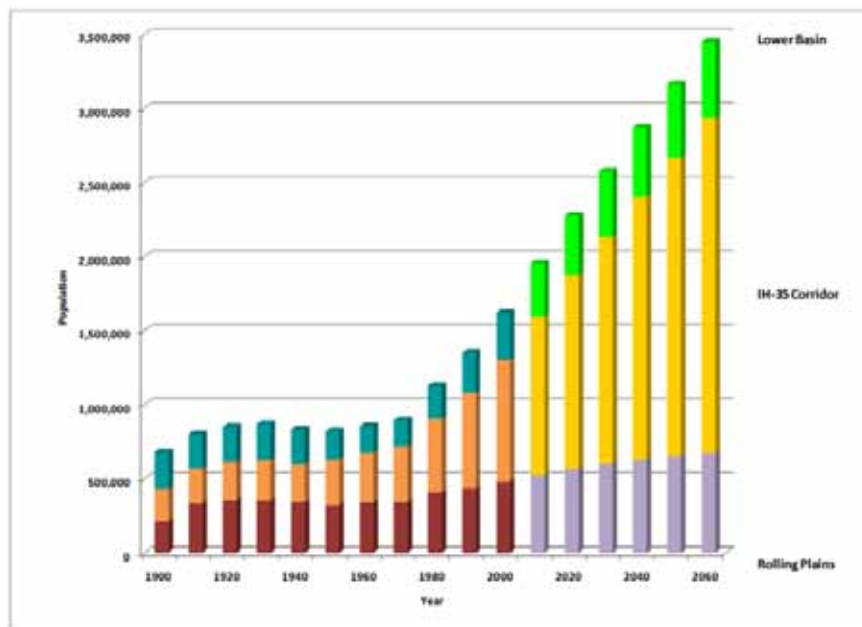
Figure 30. Fort Hood, TX.

## Regional characterization of Fort Hood\*

Fort Hood sits entirely within the Brazos G Regional Water Planning Area in Texas. This planning area includes 37 counties in central Texas that all lie mostly within the Brazos River Basin. The Brazos G Regional Water Planning Area is further broken down into three subregions. Fort Hood is within the five-county IH-35 Corridor subregion of the larger planning area. Both the natural and human systems found throughout this region shape the proposed water scenarios.

### Demographic trends

The IH-35 corridor has been growing rapidly since the 1970s at annual average rates of 3.9 percent. The current population of this subregion is estimated to be between 500,000 and 750,000. While this region contains only five of the 37 regional counties, it is expected to receive more than half of the area's future growth, at least partly due to its location along the Interstate 35 corridor, which connects Dallas/Fort Worth to more southern Texas cities including Austin and San Antonio. By 2040, the region is expected to have roughly 1.75 million inhabitants (Figure 31).



Source: Brazos G Regional Water Planning Group (2010).

Figure 31. Historical and projected populations of Brazos G subregions.

\* Unless otherwise noted, information from this section is derived from Brazos G Regional Water Planning Group (2010).

## **Water sources**

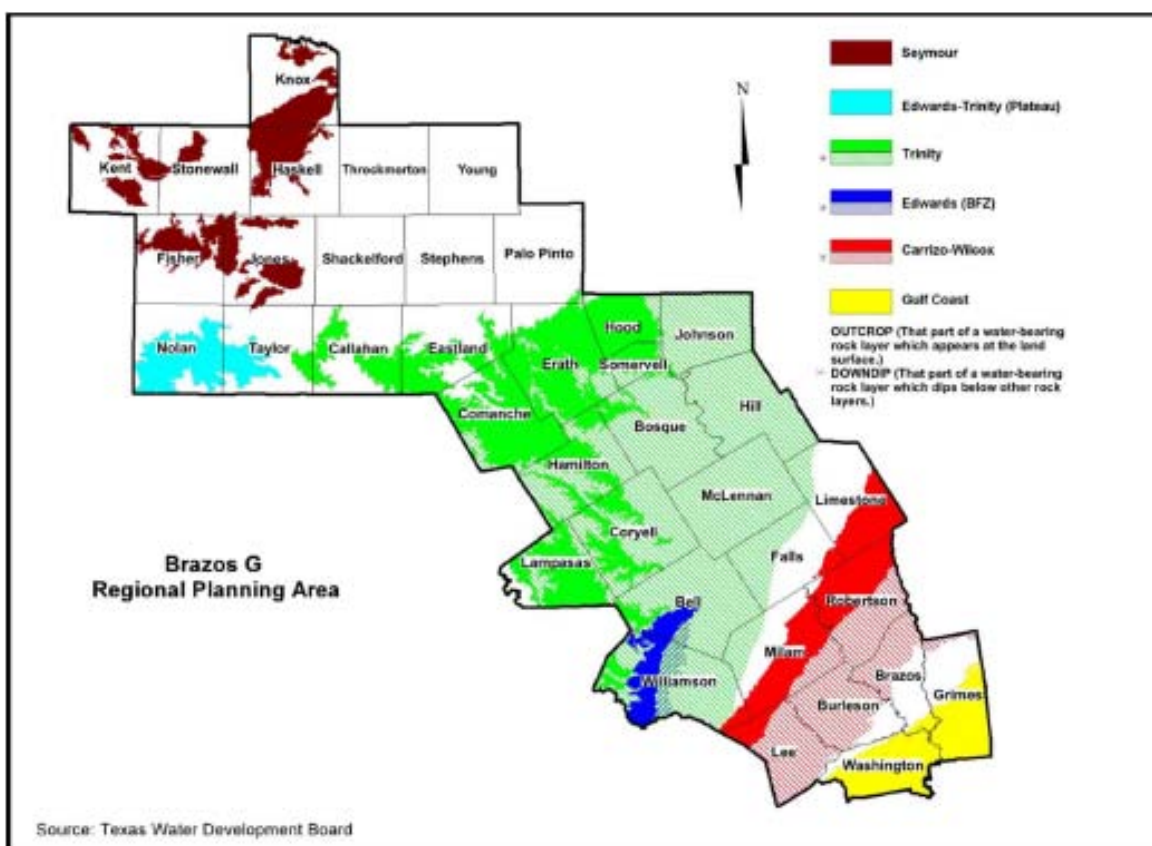
Bell County Water Improvement District (BCWCID No. 1) supplies potable water to South and West Fort Hood and the cities of Killeen, Copperas Cove, Harker Heights, and Belton (Bell Co. WCID 2010). Gatesville Regional Water Supply (GRWS) provides potable water to North Fort Hood. The City of Killeen does not treat or handle any of the installation's potable or wastewater, despite a close relationship between the two (Butler 2009).

Fort Hood's water suppliers, BCWCID and GRWS, both draw potable water from the same surface water source, Belton Lake (Bell Co. WCID 2008). The lake can hold 887,000 acre feet of water for flood control, conservation, and water supply. Water supply reserves are 372,000 acre feet of the total lake volume.

Although Stillhouse Hollow Lake is close to the installation, it does not serve as a Fort Hood water supply. The Lampasas River and its tributaries feed Stillhouse Hollow Lake.

Portions of six major aquifers extend across the Brazos G region, in addition to nine minor aquifers (Figure 32). Although situated above the major Edwards-Trinity Aquifer and minor Ellenburger-San Saba, Hickory and Marble Falls aquifers, Fort Hood does not rely on these sources, due to its location near plentiful surface water (Texas Water Development Board 2010). In addition, one recent attempt to use a well at the Clear Creek Golf Course on Fort Hood failed because neither the quantity nor the quality of the groundwater was sufficient for either a potable water source or a non-potable irrigation water source (Young 2010). According to USGS data, numerous groundwater wells do draw from the Trinity, a major aquifer, in parts of counties neighboring Bell and Coryell that share small portions of Fort Hood's watersheds, such as McLennan and Erath counties.





Source: Brazos G Regional Water Planning Group (2010).

Figure 32. Major area aquifers.

### Texas water law and regulation

The Brazos Regional Authority administers surface water rights in the Brazos G planning region. “Diversions and use of this surface water occur throughout the entire region, with over 1,000 water rights currently issued (Brazos G Regional Water Planning Group 2010).”

The Texas legislature enacted state and regional water planning with Senate Bills 1 and 2, passed between 1997 and 2001. “The SB1/SB2 legislation calls for a water planning process wherein Regional Water Planning Groups (RWPGs) are formed with members representing a minimum of 11 different interests, including the environment, industry, municipalities, water authorities, and the public” (Brazos G Regional Water Planning Group 2010: IPP 1-1). The Texas Water Development Board (TWDB) has established 16 regional water planning areas, each with its own RWPG. Each RWPG prepares a regional water plan on a 5-year cycle. The TWDB uses these to develop the state plan.

Different regulatory systems govern surface and groundwater in Texas. The state legislature authorized the Texas Commission on Environmental Quality (TCEQ), the state's environmental agency, to delineate Priority Groundwater Management Areas (PGMA's), "those areas of the state that are experiencing or that are expected to experience, within the immediately following 25-year period, critical groundwater problems, including shortages of surface water or groundwater, land subsidence resulting from groundwater withdrawal, and contamination of groundwater supplies" (Texas Water Code 2010: Section 35.007). The TCEQ may then recommend the creation of Groundwater Conservation Districts (GCD's) within the PGMA's. GCD's must then jointly plan for "desired future conditions" of groundwater resources and submit them to the TWDB, who uses them to forecast Managed Available Groundwater (MAG) (Texas Water Code 2010: Section 35.007). MAG should then be used for groundwater management and permitting.

This is a departure from the traditional "rule of capture" for groundwater in Texas, under which, in most cases, landowners could pump water beneath their land with impunity. The above-mentioned regional planning modifies this rule in the designated areas. However, Connor (2004, 3) argues that "groundwater districts will need to be more aggressive in planning efforts" in the future. Currently, the Clearwater Underground Water Conservation District oversees the installation of wells in Bell County. There is no comparable body for Coryell County (Young 2010).

Connor describes surface water law in Texas as a mix of riparian rights and prior appropriation. The state claims ownership over surface water. Users must receive permission to use this water in the form of water rights in most cases as defined by the Texas Water Code (Texas Water Development Board 2006). The water rights then follow the "first in time, first in right" rule. Users with water rights issued earlier, or those whose rights are senior for other reasons — Native American tribes, for instance — have priority for receipt of their water in drought times, when the state may issue a "priority call." Surface water also includes reservoirs that have varying storage "pools," or volumes designated for various purposes.

By law, Fort Hood can exercise Federal reserved water rights sufficient to satisfy its mission (this amounts to approximately 10.7 MGD). Despite this "legal availability," however, a lack of "physical availability" would prevent the perfection, or real-world use, of these rights (Weston et al. 1998).

## **Climate**

Both Fort Hood and the surrounding region fall into the North Central Texas climate division. The climate of this area is humid subtropical with hot summers and mild winters (Pierson 2010). The Brazos G region averages lows of about 35 F in January and highs of 95 F in July. Fort Hood and its upstream region receive 28–36 in. of rain a year, with precipitation increasing from west to east across the region. A large portion of the rain in the area comes from thunderstorms that tend to occur more often in the spring months, and that can bring heavy winds (Pierson 2010).

## **Topography**

The study area crosses three vegetation regions: Blackland Prairies, Oak Woods and Prairies, and Edwards Plateau.\* The Blackland Prairies area is characterized by gently rolling land and the dark clay found in the highly fertile area soils that give the prairies their name. The Oak Woods and Prairies consist of mixed prairies and woodlands with greater and more varied topography than the Blackland Prairies, and likewise, more diverse soils. The Edwards Plateau contains a variety of textures of soil and is underlain mostly by sedimentary rock. The area mostly contains formations of the Cretaceous era.

## **Land cover**

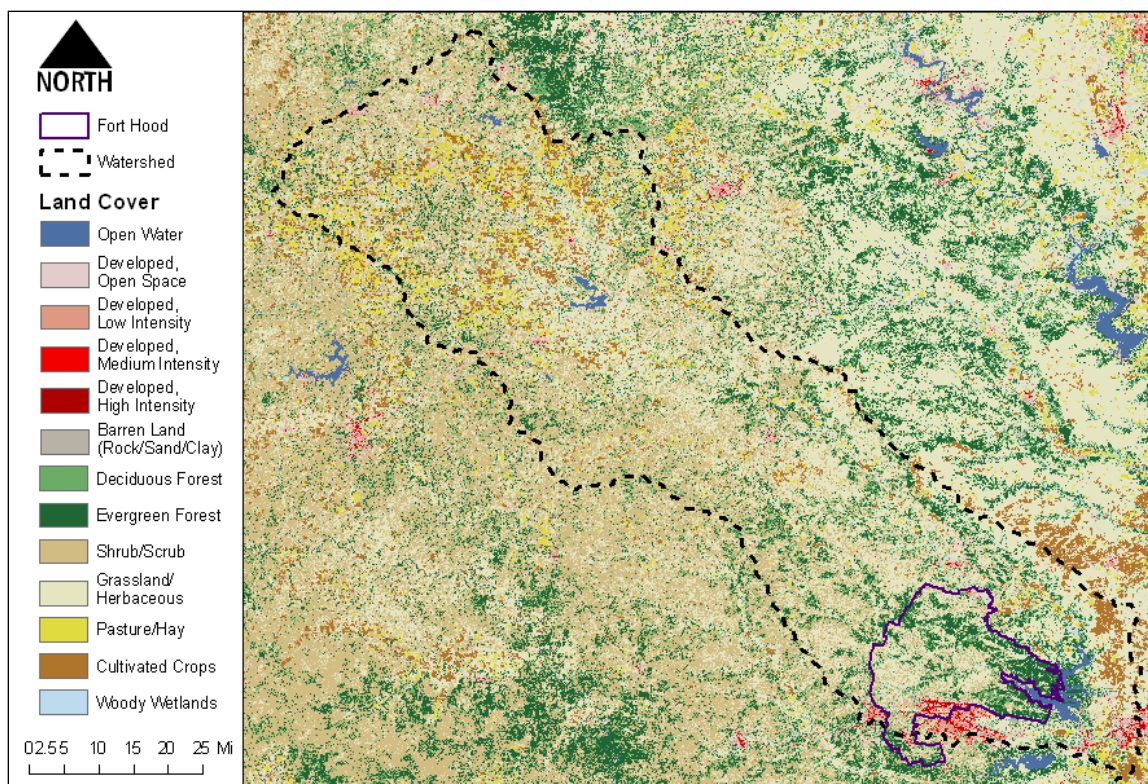
Agriculture and ranching are the traditional land uses associated with the region surrounding Fort Hood, though there are several growing cities/settlements in the area. The watershed that feeds Lake Belton (Figure 33) is dominated by land categorized as grassland and scrub. There is also agricultural and forest lands. There is relatively little developed land in the watershed; that which does exist is mostly located in the downstream end of the watershed on Fort Hood or one of the nearby cities.

## **Historic water demand**

“In the past decade, with respect to surface water, estimates indicated that the three main uses [across Texas as a whole] were broken down as follows: agriculture, 51 percent; municipal, 26 percent; and industrial, 23 percent” (Connor 2004, p 2).

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\* Vegetational regions are roughly equivalent to ecoregions.



Source: US Geological Survey, 2001

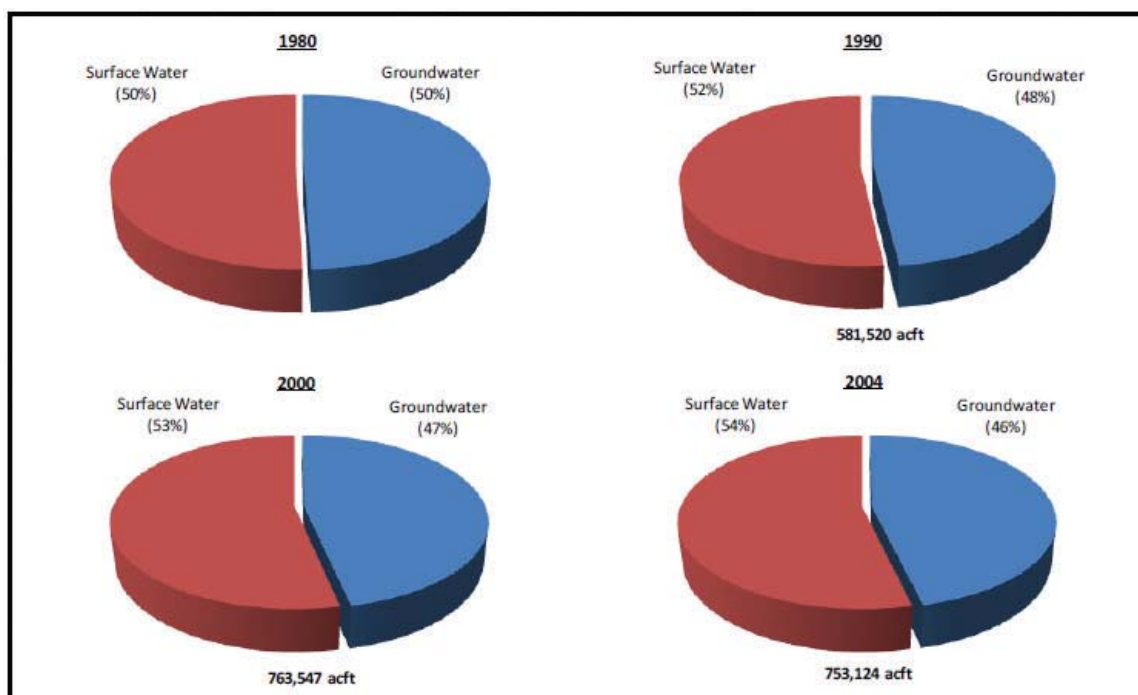
**Figure 33. Fort Hood area land cover.**

Historically, according to the Brazos G Regional Water Planning Group, “while the proportions [between groundwater and surface water in the Brazos G region] were equal in 1980, surface water use was greater by 4 percent in 1990, 6 percent in 2000, and 8 percent in 2004” (BGRWPG 2010, pp 1-13). The data shown in Figure 34 illustrate this increasing reliance on surface water.

While historical water use was predominately agricultural, regional water planning forecasts anticipate an increase in municipal use and a decrease in agricultural use between 2010 and 2040.

### **Developing the Fort Hood regional model**

This study analyzes existing data on water availability and use in the region, and projects these trends out to 2040. A series of possible scenarios for water availability in 2040 were developed. These scenarios should help both Fort Hood and the surrounding region plan for adequate water supply in the coming decades.



Source: Brazos G Regional Water Planning Group (2010).

Figure 34. Historical water usage in the Brazos G Region.

### Regional water supply model

The following section describes the rationale behind the Regional Supply Model definition. The Fort Hood region is relatively rich in precipitation, as noted above. Unlike some areas of Texas — West Texas, for instance — river water is plentiful within and around the study area. Groundwater is also present, although its usability as a potable water supply is limited by its need for considerable treatment. Only some sources that are significant in other parts of the Brazos G planning region are relevant within the study area, and then only some of those affect Fort Hood.

While study area counties use groundwater to varying degrees, surface water comprises almost 80 percent of the total. Comanche County withdraws over half of the approximately 30 MGD of groundwater in the entire study area. Fort Hood is divided between two counties, Bell and Coryell. In the latter, groundwater makes up 12 percent of withdrawals, whereas the former, by far the larger user, withdraws only 4.2 MGD of groundwater on average, or about 4 percent of its total fresh water withdrawals. Further, groundwater does not appear to significantly impact Fort Hood's water supply, since Fort Hood's potable water comes exclusively from Lake Belton.



Accordingly, the watershed boundaries of the major rivers that flow into Belton Lake define the study area for Fort Hood's Regional Supply Model. While groundwater is present in the region, it is assumed to be insignificant enough within this particular study to warrant incorporating only surface water into the model. The Leon River and Cowhouse Creek are the biggest surface water contributors to regional supply that affect Fort Hood (Table 18). They feed Belton Lake and together form the water supply baseline.

The closest useful stream gages to Fort Hood are on Leon River and Cowhouse Creek. These gages have lengthy data records that were averaged to predict future availability.\* The US Geological Survey's (USGS) National Water Information System was accessed to download flow data in cubic feet per second (cfs). The historical period varies for all the gages, but each gage record incorporated over 20 years of daily data.

**Table 18. Fort Hood study area water supply baseline.**

<b>Leon River Sub-basin Availability</b>
Runoff change
Non-basin water provision change
County demand change - Leon portion
Flow in Leon River near Gatesville, TX
<b>Cowhouse Creek Sub-basin Availability</b>
Runoff change
Non-basin water provision change
County demand change - Cowhouse portion
Cowhouse Creek at Pidcoke, TX
<b>Belton Lake Storage Inflows</b>
Leon River inflow (MGD)
Cowhouse Creek inflow (MGD)
Consumptive use
Non-consumptive use
Conversion from flow (MGD) to volume (MG) for a hypothetical baseline year
Unexplained inflow volume + existing lake volume
Lake Belton Volume (MG)

\* A gage on Cowhouse Creek near Killeen, TX, was ruled out because it only had approximately five years of data (from the 1940s).

These data were averaged for each gage and the 75<sup>th</sup> and 80<sup>th</sup> percentiles taken to represent baseline flows at these points that could then be modified by scenario factors. The percentile analysis represents an effort to capture some of the variability between peak and low flow that annual averaging obscures. Coryell Creek also contributes to Leon River flow, but no gage exists on Leon Creek below the two rivers' confluence. Thus, flow from the Leon Creek cannot be accounted for on its own. It contributes to the error term.

Many factors can alter baseline flow at any point on the river. However, in the following scenarios, runoff, change in non-basin water provision, and county demand are broken out for each gage because they have significant effects that can be differentiated across multiple scenarios.

“Runoff” in this model is a proxy for future variation in rainfall and evaporation, which are linked to climate variation. “Non-basin water provision” tracks hypothetical variation in the amount provided to users outside of the Leon River and Cowhouse Creek watersheds, as this would remove water from the local water cycle. “County demand” from the Regional Demand Model is incorporated, as any increase in water use would potentially increase consumptive use, which would also remove flow from the stream.

The Belton Lake model section sums flow at the two gages mentioned above, and then converts the flow measured in MGD to volume contribution to the lake, measured in million gallons over a hypothetical baseline year. In this baseline, “Belton Lake Volume” is also calculated from USGS reservoir volume data. “Unexplained inflow volume + existing lake volume” is the difference between this volume and the volume contributed over the year by the two rivers' inflow, less consumptive use of 41.5 percent for the Texas-Gulf region.\* This serves as an “error term” that captures unexplained lake volume resulting from other inflow, direct precipitation and evaporation, possibly other users' withdrawals, and existing storage. The gages chosen were those closest to the lake with sufficient records, but flow may enter the streams after these gages. Only gages situated directly at the lake inlet would capture all factors. In the forecast years after the baseline, this error term is derived in a different way; it is

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\* The 41.5 percent consumptive use estimate is derived from USGS water usage data from 1995. Consumptive use was not reported after 1995 because of the difficulty to accurately produce an estimate. The 2009 Fort Hood Water Conservation Plan reports that 60 percent of Fort Hood's water purchases were returned to Bell County Water Control and Improvement District as wastewater, which almost matches the 41.5 percent consumptive use estimate.

proportional to the ratio of the error term in the baseline to the lake volume in the baseline. The assumption is that the proportion of unexplained flow to lake volume in future years will remain the same as in the baseline year. This assumption allows “Belton Lake Volume” in the forecast years to vary with inflow changes.

This is a simplified analysis. This is meant to create a simple method for illustrating the potential effect of various changes on water supply, but the water rights system is too complex to be simulated in such a straightforward fashion. As such, this Regional Supply Model does not predict actual water availability. Sophisticated water planning and modeling already exist at the regional and state level in Texas to inform understanding of water supplies. This report draws attention to select points of these studies elsewhere. For costly, political, or high risk applications that need to incorporate regional water planning numbers, the more extensive, intricate, and publicly reviewed Brazos G IPP modeled estimates should be used.

### **Regional water demand model**

The following section describes the rationale behind the Regional Demand Model definition and its additional role as a factor in the Regional Supply Model.

The Regional Demand Model primarily uses base data from the USGS Water Use for the Nation dataset (2005), which details in-stream water withdrawals at the county level. The study area includes the same counties as the Regional Supply Model, but with special attention paid to the portions of the counties that fall within the study area. Counties are located in multiple watersheds so the entire demand of a single county would not fall on a single watershed, thus water use from a single county was weighted by the portion of that county that is located within the regional watershed (basin) (Table 19). The different use types reflect USGS in-stream withdrawal categories.

The Texas State Geographer’s publicly available 2008 population forecasts at the county level fill out the model’s growth projection (Texas State Data Center and Office of the State Demographer 2010). These projections were used instead of the US Census Bureau estimates because the state produced them locally and are assumed to be more accurate. The regional water planning process uses a different set of population forecasts, but they are only available in 10-year increments.



Table 19. Water use data 2005 apportionment (MGD).\*

County	Public Supply	Domestic	Industrial	Irrigation	Livestock	Ground water	Surface Water	Total	% in Basin	Basin Withdrawal
Bell	101.4	2.3	0.4	0.8	0.8	4.2	101.5	105.74	33.20	35.1
Comanche	1.9	0.8	0.0	21.9	3.3	17.7	10.2	27.93	96.57	27.0
Coryell	7.4	0.0	0.0	0.2	1.2	1.1	7.7	8.79	88.13	7.7
Eastland	2.7	0.7	0.0	7.5	1.0	8.3	3.6	11.83	66.55	7.9
Hamilton	0.0	0.5	0.0	0.5	1.5	1.8	0.8	2.66	68.93	1.8
Total	113.3	4.2	0.5	30.9	7.9	33.1	123.8	156.95		79.53

\*There was no water used for either mining or thermoelectric power in any of the study counties in 2005  
Source: US Geological Survey (2005)

The Texas Demographer's 2008 figures are in 5-year increments, which are more appropriate for interpolation than the 1-year intervals used in the Regional Supply Model. The state encourages their use for planning purposes and they are endorsed as the official Texas population estimates. It is outside the scope of this study to evaluate the population forecast method in detail or to generate a custom forecast.\* For all but one scenario detailed below, the forecasts chosen were a moderate forecast (the "0.5 Scenario") that represented half the population change of 1990-2000, a period of rapid growth the Texas Demographer thought unlikely to be sustained into the future (Population Estimates and Projections Program 2009).

In years after 2005, increased withdrawals are forecast. They vary with expected population growth based on the aforementioned projections, but agricultural use for irrigation decreases with population growth under the assumption that rising municipal populations and growing urbanization will continue the national trend of farmland conversion for development. For each year, all categories are summed, and counties are also summed for a regional total (Table 20).

These demand forecasts feed the Regional Supply Model's "County demand" cell. Only part of each county may fall within the study area, and this part is often split between the Leon River and Cowhouse Creek watersheds. ESRI's ArcGIS mapping software enabled computation of these areas, which were used as weights.

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\* The Texas Demographer's forecasts use a cohort-component method, a sophisticated method for simulating future population through births, deaths, and migration. The version in use here incorporates various details and assumptions to hopefully achieve greater accuracy, although it is unclear whether it uses the common "net migration" approach which may lead to reduced accuracy. See Isserman (1993) for a critical discussion.

Table 20. Regional demand model results (MGD).

	2005	2010	2015	2020	2025	2030	2035	2040
Bell	105.0	114.6	123.8	132.5	140.7	149.2	157.9	166.1
Comanche	28.0	27.9	27.7	27.5	27.4	27.3	27.2	27.3
Coryell	8.7	9.3	10.0	10.7	11.3	12.0	12.7	13.2
Eastland	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
Hamilton	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Totals	156.0	166.2	175.8	185.0	193.7	202.8	212.1	220.9

The Regional Demand Model apportions the effects to the correct watershed, separate from the weights used to apportion water demand to that within the region of study and that outside of it. All demand is assumed to occur at the gages near the subject counties for uniformity and then passed to Belton Lake, although in many cases this demand occurs from Belton Lake. Although this model cannot account for them, water rights also affect withdrawals throughout the watersheds.

The results of the Regional Demand Model are used in all but one of the five future water scenarios for the Fort Hood region. Scenario 5 differs in that it relies on water demand growth rates derived from the Brazos Region G Initially Prepared Plan (IPP), which is a publicly released regional water plan draft for the 2011 planning cycle (Brazos G Regional Water Planning Group 2010). The state refers to them during development of the state plan and officials base water resource infrastructure and management decisions on regional findings and agreements.

Texas Water Development Board demand projections explicitly account for the technologies used in manufacturing, mining, irrigation, and livestock watering processes and, potential future efficiency gains (Brazos G Regional Water Planning Group 2010). They also take into account future conservation assumptions based on state law. Therefore, consumptive use is not subtracted from flow in the Belton Lake section of Scenario 5 because the demand rates change already incorporate consumption.

#### **Fort Hood installation demand model**

The following explores the water use on Fort Hood, including a description of the installation's water sources the method used, and the results of the Fort Hood water demand projection

*Fort Hood water sources*

BCWCID No. 1 delivers water to Fort Hood from Belton Lake using the Army's retained water rights. No difference is made between Army water and water supplied to municipal customers. The diversion allowance for Fort Hood is 12,000 acre feet per year, consisting of one right dated 24 August 1953 for 10,000 acre feet and one dated 23 August 1954 for 2,000 acre feet (Fort Hood Water Conservation Plan 2009). This amounts to about 3,913 million gallons a year or 10.7 MGD on average. Although military installations have legal priority for water needed to support mission sustainment, installations are encouraged to handle water resource management and adjudication in cooperation with other local users, rather than preemptively.

The Gatesville Regional Water Supply that serves the North Fort Hood system also draws water from Belton Lake, but this is a small portion of overall installation use. However, this use is likely to increase in the future.

*Installation demand model*

The detailed assumptions and inputs of the Installation Demand Model follow. The model incorporates Fort Hood real property data and average water use by structure type to forecast future consumption.

Table 21 lists the inputs to the Installation Demand Model used to calculate baseline water use for Fort Hood. The baseline water use was estimated from 2008 data with less data from 2007 and 2009. "Barracks Units" and "Housing Units" come from real property data provided by Fort Hood DPW. These are not number of dwelling units, but numbers of soldiers and residents. "Military Stationed," "Transient Population," "Dependents," and "Civilian Workforce" come from the Army Stationing and Installation Plan (ASIP).

"Deployment Factor" for barracks is taken from the Fort Hood Water Conservation Plan. This factor represents the average occupancy level of existing housing on-installation. Vacancy can be due to troop deployment or training movement. A factor of 0.80 means that 80 percent of the housing is occupied or 20 percent is vacant on average over a given year.

Table 21. Fort Hood installation water demand model inputs.

	Baseline
Barracks Units	16,976
Housing Units	6,336
Military Stationed	52,781
Transient Population	525
Dependents	25,546
Civilian Workforce	16,077
Typical Military Family Size	2.01
Deployment Factor: Family Housing	0.80
Deployment Factor: Barracks	0.80
Industrial/Maintenance Factor	1.00
Storage Growth Factor	1.00
High Water Use Facilities Factor	1.00
Irrigated Land Factor	1.00
ET (Moisture Deficit Factor - in.)	56.25
Losses Factor	0.08

The growth factors below (“Industrial/Maintenance” through “Irrigated Land”) are all set to the default of 1.00. Installation planners and staff who know the Master Plan can adjust these by percentage (i.e., 1.25 in a given year for Storage means that, for this type of facility, 25 percent more buildings will exist than in previous years). This will affect overall water use and can be adjusted with as much detail at the annual level as desired.

“ET” is a “moisture deficit” factor that represents region-specific evapotranspiration. Here, this is 56.25 in. average yearly lake surface evaporation.\*

“Losses” factor represents percentage of water lost in transit through pipe leaks. Fort Hood’s is low due to work previously completed auditing and repairing the system in conjunction with Construction Engineering Research Laboratory (Fort Hood Water Master Plan 2007).

Table 22 lists baseline consumption in gallons per unit per day (gpud) by type of real estate. In most cases, the unit is the building, although in some cases the unit is per capita (family housing, barracks). The model has the capacity to use square feet; however, water use data for the installation are not available in square feet. The 94 gpud for housing and barracks is based on reported numbers for average per capita residential water use in relatively nearby Austin, TX (Walton 2010).

\* This figure, from the Texas Water Development Board, is for lake surface evaporation across the region’s reservoirs which introduces error because evapotranspiration from other surfaces differs. This was the best available estimate. “Evaporation rate varies with temperature, wind speed, humidity, and atmospheric pressure. The rate of evaporation is also affected by the surface to volume ratio of the water body: a water body with a large surface area will evaporate more quickly than the same volume of water with a much smaller surface area” (Institute of Water Research 2003).

Table 22. Baseline water consumption by unit.

Consumption (gpud)	Baseline
Family Housing	94
Barracks	94
Dependent Schools	31
Medical	7,936
Industrial/Maintenance	2,045
Lodging	150
Admin/Moderate Users	1,204
Community and Commercial: Non-food related (indoor)	629
Community and Commercial: Food-related	906
Storage	10
High Water Use Facilities	500

Other factors are calculated from the number of buildings in real property data and installation water plans where possible (e.g., schools and medical), or based on rules of thumb from the American Water Works Association where calculations are not possible. These assumptions are a source of error. Efforts in the future to meter buildings will improve the model's accuracy. "High water use facilities" are based on a general rule of thumb because this category is so varied. Detailed information on pool water use, laundry services, the golf course, and irrigation would improve accuracy. Those facilities that recycle water, the Central Wash Building and the Wash Platform, are excluded from the analysis.

The Installation Demand Model also contains a "Costs" spreadsheet. It uses Fort Hood's 2009 water rates. The model does not associate these rates with specific building types because this level of detail is unavailable. The rates are applied instead to all building types in the Cost Projection spreadsheet. In practice, "rate A is for mission support, for example, the Post Exchange, commissary and the hospital. The golf course is included in this category. Rate H is for all family housing. Rate B is for all others, i.e., contractors, builders, etc." (Jenicek et al. 2009). These rates populate the "Cost Projection" worksheet.

#### *Installation demand model results*

The baseline water use estimate calculated for 2008 is 6.31 MGD, whereas the installation's actual billed water use for FY08 is 6.3 MGD. This match between the estimated baseline and actual use is coincidental. The baseline was used to project the demand for Fort Hood out into the future (Figure 35).

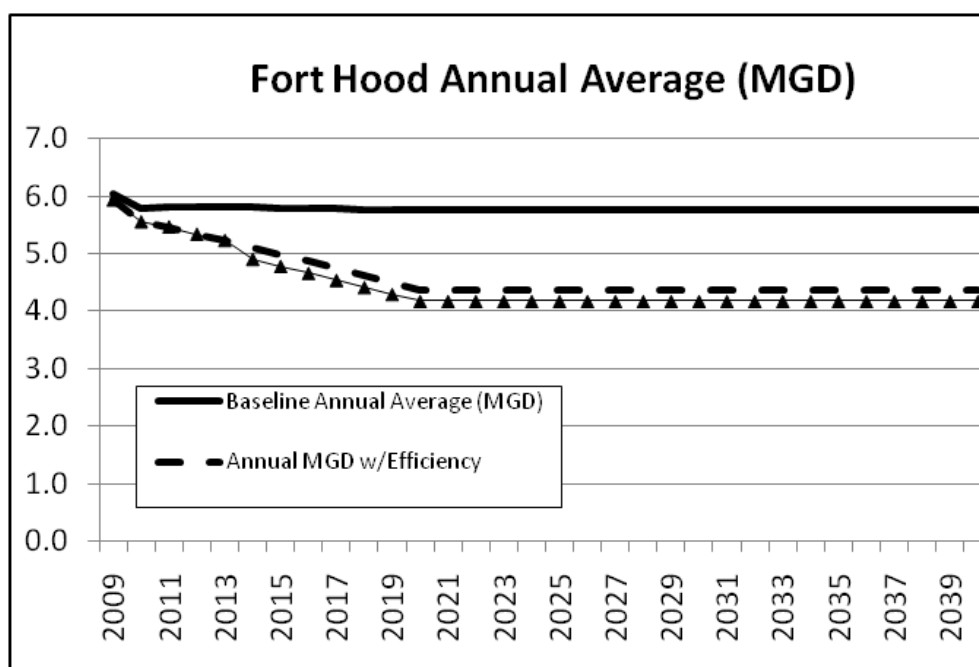


Figure 35. Fort Hood demand model results.

The “baseline annual average” represents projected water demand for the installation if water use were to continue to follow current trends. “Annual MGD w/efficiency” represents the projected water demand for the installation should water efficiency measures be put in place in compliance with E.O. 13514. The “annual average w/golf course reuse” represents the projected demand assuming that reuse of water for golf course irrigation is introduced in addition to the water efficiency measures necessary to comply with E.O. 13514.

### Fort Hood 2040 water availability scenarios

The objective of this study was to project water availability 30 years into the future. Therefore the baseline water supply and demand were projected to the year 2040. The potential for water scarcity was reviewed under various alternate scenarios to better account for future uncertainty.

#### Scenario 1 – Extreme climate change

Scenario 1 poses a “what-if” about climate change. What would the effect on water supply be if the more extreme predicted climate change effects occur? Climate models forecast potential impacts to median annual runoff volume under low and high emissions. This scenario uses the high-emissions forecast of a potential 10 percent decrease in runoff volume given the effects of rainfall reductions and temperature rise in the Fort Hood

area. This factor carries the assumption that the reduction occurs in the total flow at the Leon and Cowhouse Creek rivers gages. Both rivers have a base flow or a flow from shallow groundwater. The volume of shallow groundwater flows is not available and is thus not included in any of the scenarios. Much of the rivers' normal flow likely results from runoff in this relatively water-rich region, although this may not be the case during a drought.

Consumptive use may change over time given changing runoff and temperature. Potential changes are not quantified in the literature so consumption is assumed to remain constant across all the scenarios, but Scenario 5, which uses Texas Water Development Board demand forecasts that already incorporate consumption.

Forecasting precise climate change effects on river flows is impossible. In addition, the presence of complex water rights complicates what the actual impact will be on available water flows. Neighboring areas may claim more of their water rights if they are senior or they may purchase additional unallocated flow. The assumption here is that 10 percent more water could leave the basin in the future, although review of regional planning documents can give a more nuanced understanding, county-by-county.

As explained previously, change in county demand is based on the Regional Demand Model, which uses USGS water withdrawal data (US Geological Survey 2009) and Texas State Demographer population projections to forecast water demand into the future (Texas State Data Center and Office of the State Demographer 2010).

### **Scenario 2 — Greatly increased demand**

Scenario 2 is a “what-if” related to water demand. The previous scenario described what could happen if users outside the Leon River and Cowhouse Creek sub-basins desired 5 percent of the water now with their use increasing gradually over the years until 2040. It also used a climate change scenario of 10 percent reduction in runoff, which reflects a more extreme possibility. The scenario is based on low-emissions climate change with a 5 percent reduction in runoff. Scenario 2 also explores what could happen to water availability if demand increased greatly because of unexpectedly high population growth, unanticipated in-migration, unanticipated industrial needs, or slower conversion of irrigated land into municipal use. This could change both in and outside of the basin. The Texas State Demographer projections used in the other scenarios presented here

are based on halving the 22.8 percent overall state growth rate for 1990 to 2000. Using 11.4 percent is the recommended moderate growth rate because 1990 to 2000 decade was a period of very rapid growth that the Texas State Demographer considers unsustainable (Texas State Data Center and Office of the State Demographer 2010).

The change in county demand in Scenario 1 uses an 11.4 percent growth rate. Accordingly, change in county demand and change in non-basin water provision are doubled in Scenario 2. While the results produced by this method of doubling probably differ somewhat from the results produced if the population counts from the 1990-2000 scenario were used in the regional demand model itself, this method is faster and allows general exploration of a plausible higher demand scenario, which is the goal.

### **Scenario 3 — Status quo**

Scenario 3 is the Regional Water Efficiency scenario. The low-emissions climate change prevails and demand inside and outside the basin follow the same pattern as Scenario 1. Added to these factors is a 2 percent year-on-year reduction through 2020 in water demand both inside and outside the basin. This explores the results of a water conservation policy like that required of the Army by E.O 13514 adopted throughout the region.

### **Scenario 4 — Total water management**

Scenario 4 is the Total Water Management (TWM) scenario. TWM is a way of thinking about water planning that aims for the most efficient, most socially and environmentally beneficial allocation of water resources (see Jenicek et al. 2009, p. 33) TWM seeks to optimize water use within a watershed rather than approaching water use discretely for each water user.

In this model, the TWM scenario means greater water conservation, which plays a prominent role in this approach to decisionmaking. In the Regional Supply Model, this means a 6 percent year-on-year reduction in water withdrawals through 2040 in place of Scenario 3's reduction rate of 2 percent. While not based on an existing regional plan, this assumption serves as a lower water use limit test.

The TWM scenario's effect on the Installation Demand Model is shown through water reuse on the installation's golf course. Clear Creek Golf Course used 97.6 MG (0.27 MGD avg.) of potable water in 2009. A study conducted by the Construction Engineering Research Laboratory for Fort



Hood's Directorate of Public Works proposed 58.8 MG (0.2 MGD avg.) of non-potable water reuse to supplement potable water. This project costs \$654,000, with electricity costs estimated at 2 to 3 percent of the value of the water pumped. The simple payback period is 3 years for the capital cost (Scholze 2009). In the Installation Demand Model, the TWM line includes this reduction beginning in 2014.

### **Scenario 5 — Brazos G water demand numbers**

Scenario 5 builds on Scenario 2's supply assumptions, including a runoff decrease of 2 percent, but with a change in non-basin water provision equal to only 2 percent. The change was made not to explore greatly increased demand as in Scenario 2, but demand that changes roughly in line with the Brazos Region G planning forecasts for demand. However, the scenario does not follow the annual Brazos Region G planning forecasts. Instead, the percent change in demand from 2005 to 2040 is aggregated by sub-basin. County demand is then adjusted against the 2005 baseline that is drawn from the Brazos G data. The demand forecasts already incorporate consumptive use. Thus, the scenario assumes consumptive use from Belton Lake is zero, although actual consumptive use is not zero, but because Leon River and Cowhouse Creek total flow already includes consumptive use.

### **Scenario results**

The Belton Lake volume (Table 23) is the sum of flow at the two gages (mentioned in the Regional Supply Model section) converted into million gallons (MG) to show simulated volume contribution of the Leon River and Cowhouse Creek to the Lake.

Three baselines were determined based on the mean, 75<sup>th</sup>, and 80<sup>th</sup> percentiles of daily average streamflow measured by the USGS. While the mean is used to draw the following conclusions, the other percentiles are provided for comparison because of peak flows during storms that skew the mean higher.

The inflow into Belton Lake is important because this inflow serves as Fort Hood's primary water supply, which the installation shares with other Bell County Water Control and Irrigation District #1 customers. While the model does not directly predict existing storage and water availability, changing average inflow is one important component of the water supply.

Table 23. Scenario expressed as Lake Belton volume in regional supply model.

Lake Belton Volume — Regional Scenario						
	Scenarios — Year 2040 in MG					
	Baseline	One	Two	Three	Four	Five
Mean	117,872.4	91,022.8	62,436.8	99,369.1	101,110.6	197,966.4
75 <sup>th</sup> Percentile	144,840.8	69,487.3	23,102.0	77,946.8	80,381.5	175,169.4
80 <sup>th</sup> Percentile	145,557.6	87,662.4	58,878.7	95,807.1	97,540.7	191,884.3

## Water sustainability assessment for the Fort Hood region

This study was undertaken to assess water sustainability for Fort Hood and the surrounding region that affects Hood's water supply. However, the water rights system is too complex to be simulated. Thus, the Regional Supply Model cannot predict actual water availability.

While actual water availability in the region cannot be precisely predicted, the scenarios do examine the effect—in terms of magnitude and direction—of different stressors on water resources. Belton Lake's mean volume forecasts assume that water contributed by the model variables affect volume directly without the influence of lake management policies. Not all of the water would necessarily be available to BCWCID to serve customers. However, the forecasts show relative effects.

Extreme climate change under the model's assumptions could reduce average water volume in the lake by about 91,022 MG by 2040. Greatly increased demand could decrease it even more. Whether a level as low as Scenario 2's would be allowed is unknown. With growing population and water demand in the region, it is a best practice to secure the future stability of the installation to continue to implement more aggressive efficiency practices. Although much of the Brazos G region is not expected to experience the same shortages as other regions in Texas, installation personnel should continue to allocate time to participate in the state's regional water planning process. The Brazos Region G 2010 Initially Prepared Plan shows Fort Hood with a surplus of water available through 2060, but some users around it must implement plans to satisfy an estimated deficit by 2060. These include the City of Killeen, which plans to conserve and purchase 5365 acre feet more from BCWCID No. 1 by 2060 (Brazos G Regional Water Planning Group 2010).

Fort Hood's success at implementing water conservation measures has the potential to make it a leader among the surrounding communities in the

pursuit of regional water security. Many buildings on the installation are already metered (Fort Hood Directorate of Public Works 2009). New buildings must be metered and continuous meter reading and water use tracking will enable full water audits once all buildings come online. Fort Hood now installs low-flow water fixtures in buildings being renovated. Contract specifications also include such standards (Fort Hood Directorate of Public Works 2009.). The proposed Clear Creek Golf Course project would evaluate alternate water supplies. Continuing the positive effect of efficiency measures and the need to meet Federal mandates, these standards and plans should be regularly updated to include new models and specifications as feasible.

## **7 Fort Irwin, California\***

Fort Irwin and the National Training Center (NTC) is an Army training installation located approximately 37 mi to the northeast of Barstow, CA in San Bernardino County. Established in 1940 as the Mojave Anti-Aircraft Range, and designated as a permanent installation in 1961, the current mission of the NTC is to provide realistic joint and combined arms training. Fort Irwin has seen periods of deactivation and, from 1972 until late 1980, was used primarily as a training area by the National Guard and reserve components. Fort Irwin returned to active status in 1981 and now serves as the Army's premier training center.

Fort Irwin contains over 1600 buildings and occupies approximately 763,477 acres in the Mojave Desert. Midway between Las Vegas, NV and Los Angeles, CA, the installation is surrounded by desert hills and mountains. Fort Irwin's estimated population in 2009 was 22,287 apportioned as follows: approximately 21 percent rotational soldiers, 21 percent assigned military, 33 percent family members, and 25 percent civilian workforce.

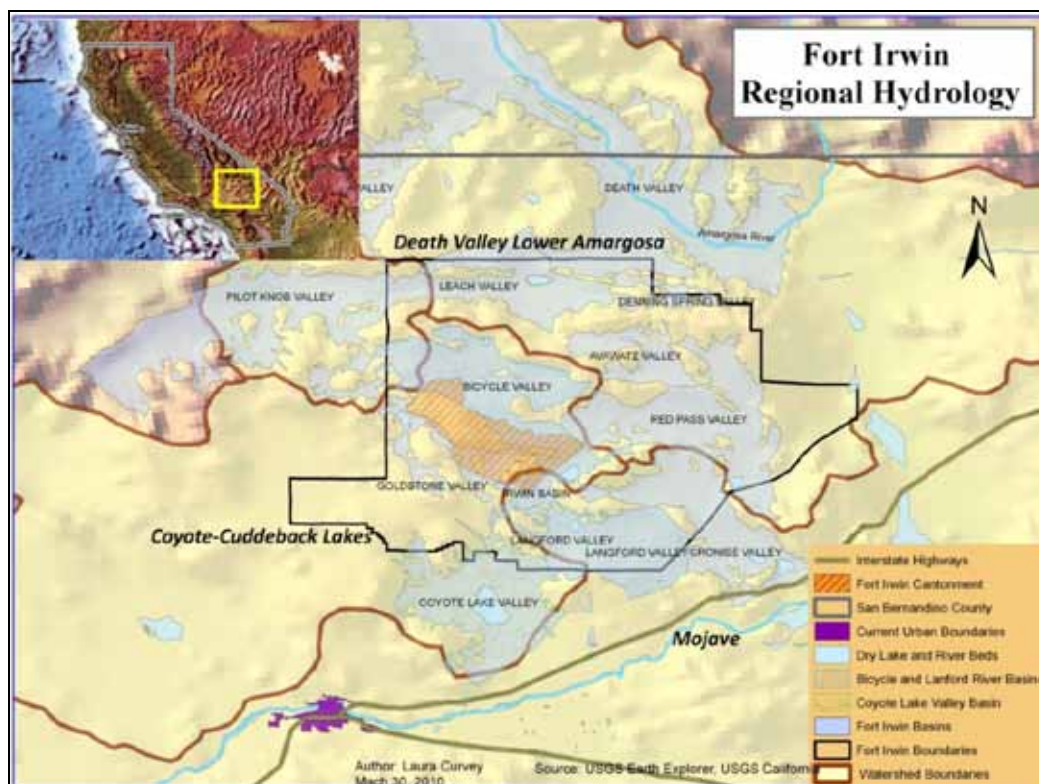
The permanent population was recently projected to double from its current size, in order to increase training rotations from 10 to 12 annually, in support of overseas operations (US Army 2008). However, Army needs were re-assessed and the Fort is currently planning to reduce the number of active service members by 300 by using 150 additional civilians and contractors to meet the increased training needs.

### **Regional characterization of Fort Irwin**

Fort Irwin is located in the South Lahontan Hydrologic Region of California, an area covering 26,732 sq mi, which receives an average annual precipitation of 10 in. per year (California Department of Water Resources 2009). Fort Irwin and its surrounding basins only receive 4.4 to 6.6 in. of rain per year on average, due to its location in the Mojave Desert, geologic barriers, and dry climate, with most of it falling during the winter months. All of Fort Irwin's water supply comes from groundwater. The low rate of natural water recharge constrains Fort Irwin's current water sources (Densmore 2003).

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\* Information for this chapter is taken from the Fort Irwin website.



Source Data: USGS, US Census Bureau, California DWR

Figure 36. Fort Irwin regional hydrology.

### Current water supply

Fort Irwin uses water solely from basins located within or connected to the boundaries of the Fort. Pumping from basins that straddle Fort Irwin's boundaries will have significant legal ramifications due to existing water rights not controlled by the installation. Mountainous topography creates transportation and energy challenges in moving water from one basin to another.

Within Fort Irwin's 1,192 sq mi perimeter lie parts of four different watersheds: the Panamint Valley, Coyote-Cuddleback Lakes, Lower Amargosa, and the Mojave (Figure 36). Except for the Panamint Valley watershed, each of the watersheds intersects near the center of Fort Irwin's training area. Within the Coyote-Cuddleback Lake and Mojave watersheds are three water basins that supply water to the installation: the Fort Irwin, Bicycle, and Langford water basins. Fort Irwin's water supply comes exclusively from five wells that draw from these basins. Additional basins located within Fort Irwin boundaries that could supply Fort Irwin with water are the Coyote, Leach, Cronise, Red Pass, Pilot Knob, and East Langford. At present, Coyote Basin is considered the most attractive future

water source due to both water availability and the construction cost of facilities and pumping (CH2MHill 2007).

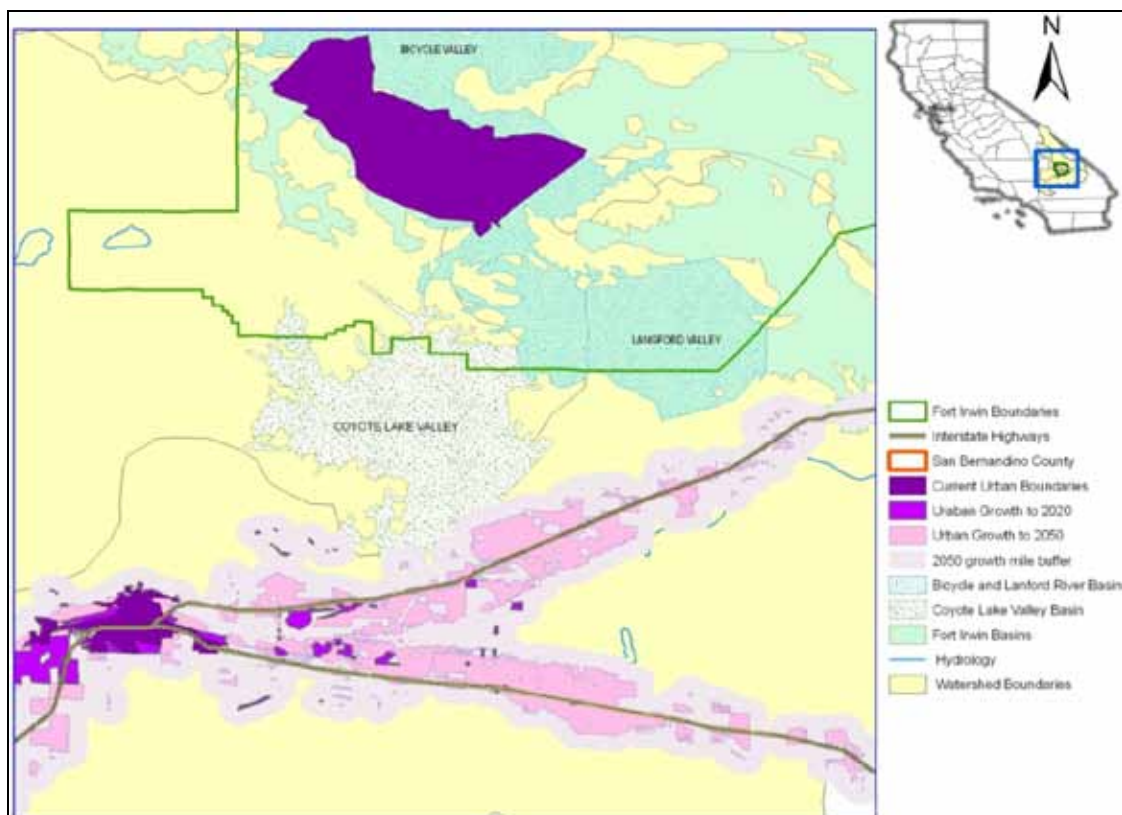
Fort Irwin's water supply beginning in 1941 was drawn from two aquifers within the Fort Irwin Basin beneath the installation. As the Fort grew and more groundwater was withdrawn, the water table decreased. By 1967, Fort Irwin began pumping water from Bicycle Basin to the northwest. In 1992, it also began pumping from the adjacent Langford Basin, south of the installation. As a result of wastewater percolation and increased pumping from adjacent basins, the water table of the Fort Irwin Basin has risen. The estimated water capacity of both Langford and Bicycle Basin is between 20,000 and 100,000 acre feet. Since pumping began, the groundwater level of Bicycle has decreased by 80 ft and that of Langford has decreased by 10 ft (CH2MHill 2007).

### **Demographic trends**

San Bernardino County's current population is about 2.1 million. This region has seen extreme growth in the last 50 years and the county's population is forecast to grow by 3.3 million by 2040 and 3.6 million by 2050. The installation is located in an isolated part of San Bernardino County and regional population growth may have a minimal effect on water available to Fort Irwin.

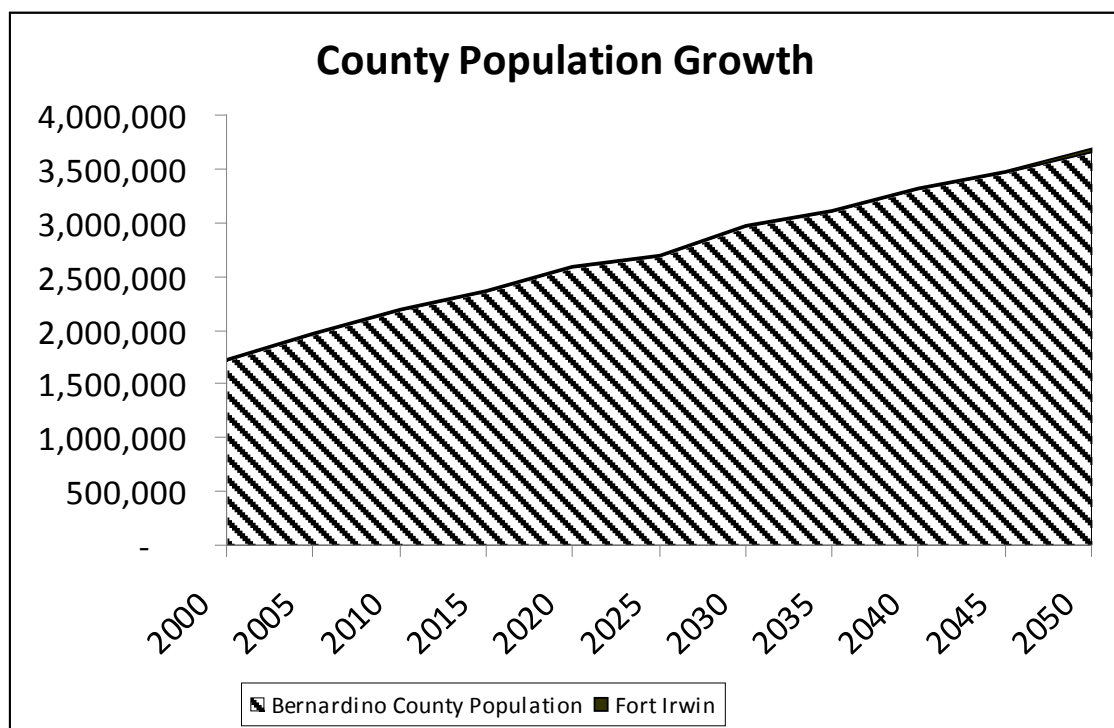
2050 population projections were developed by the State of California's Department of Finance using a baseline cohort-component method to project population by age, gender, and race/ethnicity (California Department of Finance 2007). Data from the 2000 decennial Federal census were used as the base reference year (US Census Bureau 2010). Figure 37 shows the gradual population expansion within the county as it grows following major transportation veins.

Regional growth is expected to be steady over the next 40 years with most growth concentrated in nearby existing urban areas until 2020. From 2020 to 2050, much of the growth will push out along transportation corridors into areas with few new or existing water sources (Figure 38). This figure shows Fort Irwin population as the black line at the top of the area plot. As urban areas expand, stormwater runoff is less likely to percolate into the already dense soil structure due to impervious surfaces. This may increase the already high rate of evapotranspiration and reduce recharge of existing basins.



Source: California Department of Finance 2007 & USGS data files.

**Figure 37. Fort Irwin regional population growth to 2050.**



Source: California Department of Finance 2007

**Figure 38. San Bernardino population growth to 2050.**

Although Fort Irwin's population is not expected to change in the foreseeable future, growing competition from the county for water supplies could result in new legislation regarding water supply from adjacent basins that extend outside of the Fort. Fort Irwin's current water supply is geologically disconnected from the surrounding basins from which San Bernardino County draws groundwater. However, if Fort Irwin plans future water withdrawals from Coyote Basin it will face competition for the same groundwater from expanding urban areas near its borders. State water legislation is already restrictive and is expected to become more so.

The Mojave Water Agency (MWA) currently holds administrative authority over the distribution of water to the southern extent of Fort Irwin, which includes Coyote Basin. The MWA is enjoined by law and constrained from allowing any of the interior basin water to be transported outside the MWA borders. If Fort Irwin were to attempt to use Coyote Basin as a source it would in effect be transporting water outside the MWA basin area.\*

### **California water legislation**

California's water infrastructure is both famous and infamous for its scale and for the lack of legal impediments to water overuse in naturally water scarce regions. An example of this can be seen in the operation of the MWA. The key objective of the MWA is to ensure current water demand is met, despite the region's historic overdraft of groundwater supply, thereby pumping water from exterior locations to meet this objective (MWA 2004). The extreme to which California has drained its existing water sources has recently been highlighted due to the drought that began in 2006 and is expected to continue through 2010. Despite the monsoon-like weather that created mudslides throughout southern California in early 2010, water reserves in the state are severely depleted and current precipitation produces below-average hydrologic conditions (California Data Exchange Center 2010). A water bill passed by the California state legislature in November 2009 has finally pushed for mandatory metering by all local users in the state and requires a 20 percent reduction of urban water consumption (Sullivan 2009).

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\* The constraint is based on a court ruling in 1996 that established water management policy for the area based on historic over-drafting of groundwater since the 1950s (Mojave Water Agency 2004).



### **Local water system**

Fort Irwin's water treatment system is privatized and operated by CH2MHill, although the water distribution piping is still owned by the Army. CH2MHill currently provides the installation with water from the main water treatment plant, which draws from five pumps from the three basins. Irwin Basin has one pump, and Bicycle and Langford Basins have two each. A new water treatment plant is being constructed to process brackish water and to increase the overall efficiency of the water treatment process. The new plant will be activated sometime in 2011, when the price per 1000 gallons is expected to increase by 300 to 400 percent as the result of higher operational costs (Woodruff 2010).

Fort Irwin has meters on many of its buildings and housing, but does not regularly read them. Housing consumption estimates are based on square footage. Valleycrest Landscape Maintenance is contracted to maintain landscaping throughout the base housing, but does not report irrigation water usage. CH2MHill and Valleycrest both meter the cantonment sites they irrigate; Valleycrest records were unavailable for this study. CH2MHill estimates that 6 MG/month of freshwater are used for their irrigation sites, which are estimated to be half of the overall area irrigated. Water consumption measurements are available at the main pumps and wastewater treatment plants. Other water use is estimated based on the square-footage of buildings. In addition to landscape irrigation as a major water demand, other water uses include the Remote Unit Bivouac Areas (RUBAs), field camps situated within the remote training sites of Fort Irwin's borders. Contract water suppliers have unlimited access to water taps, using tanker trucks to transport water to the RUBAs. Water use at the dispensing stations and in the RUBAs is not metered. Neither the contractors nor the rotational Soldiers are briefed on the limited water resources or on the need to conserve water (Woodruff 2010).

### **Climate and water re-charge**

Fort Irwin's climate is typical of the surrounding Mojave Desert. Summers are usually hot and dry and winters mild with very little precipitation. The Fort Irwin area averages around 6.5 in. of precipitation annually. Available precipitation varies from 2 to 11 in. annually. Precipitation mostly occurs during a few intense storms during the winter months. Little or no precipitation is seen during the summer (Densmore 2003).

### **Geography and geology**

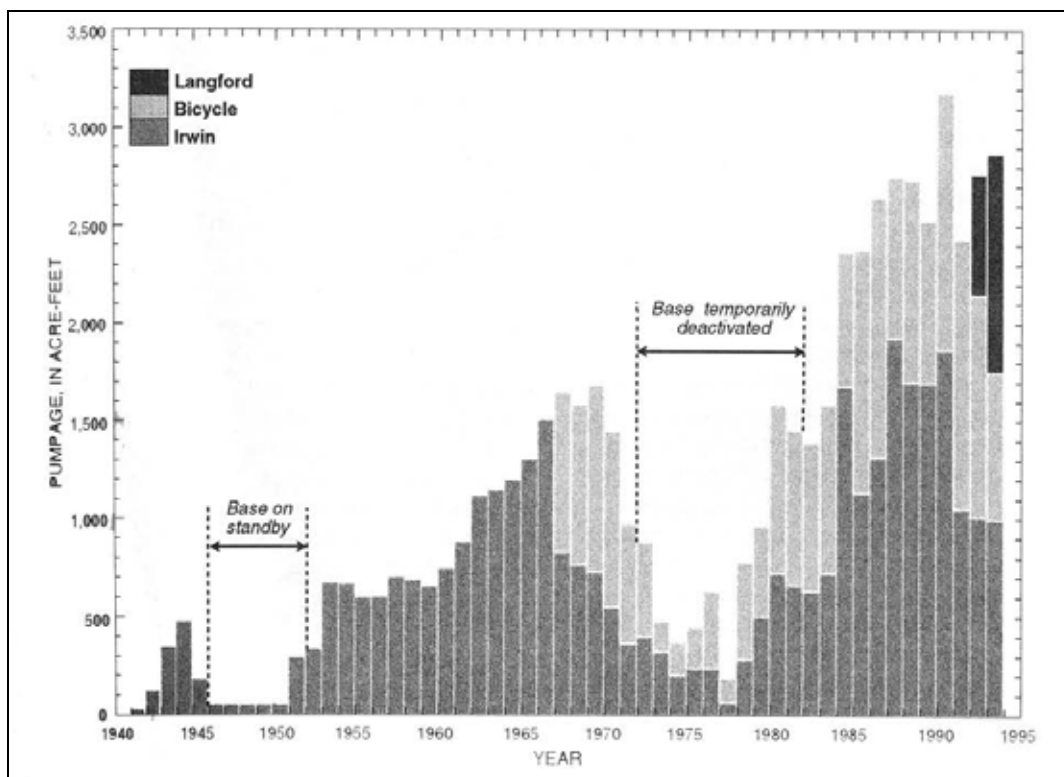
The Langford, Bicycle, and Fort Irwin water basins are composed of up to two layers of deposits. The top layer consists of younger Quaternary alluvium made up of unconsolidated to semi-consolidated deposits where moderate amounts of water-bearing material are located. Deeper down, older alluvial deposits exist, consisting of sand, gravel, and clay. The older alluvium yields moderate amounts of water. Also, some parts of these basins consist of low-permeable lacustrine deposits, which do not contain much water. Much of the younger alluvium layers are above the water table, however, areas of saturation are usually in the center of the basins. For Langford Valley basins, much of the water pumped comes from the younger unconsolidated alluvium layer. For Bicycle and Fort Irwin Basins, the water pumped comes from the older alluvium (Densmore 2003, Department of Water and Sewer 1962, US Geological Survey 1986).

### **Land use and training**

Fort Irwin encompasses 763,477 acres of the Mojave Desert, with 13,743 acres comprising the cantonment area. The National Training Center at Fort Irwin supports preparation of troops for overseas deployment. Maneuvers and mock battle scenarios are played out in the wide expanses of the surrounding Mojave Desert. Many of the Soldiers in training are based at a Remote Unit Bivouac Area (RUBA). Each RUBA may house 1000 to 6000 troops. Water for laundry, cooking, cleaning, and showering is supplied to the RUBAs by tanker truck. Each troop rotation stays at the RUBA for two to six weeks.

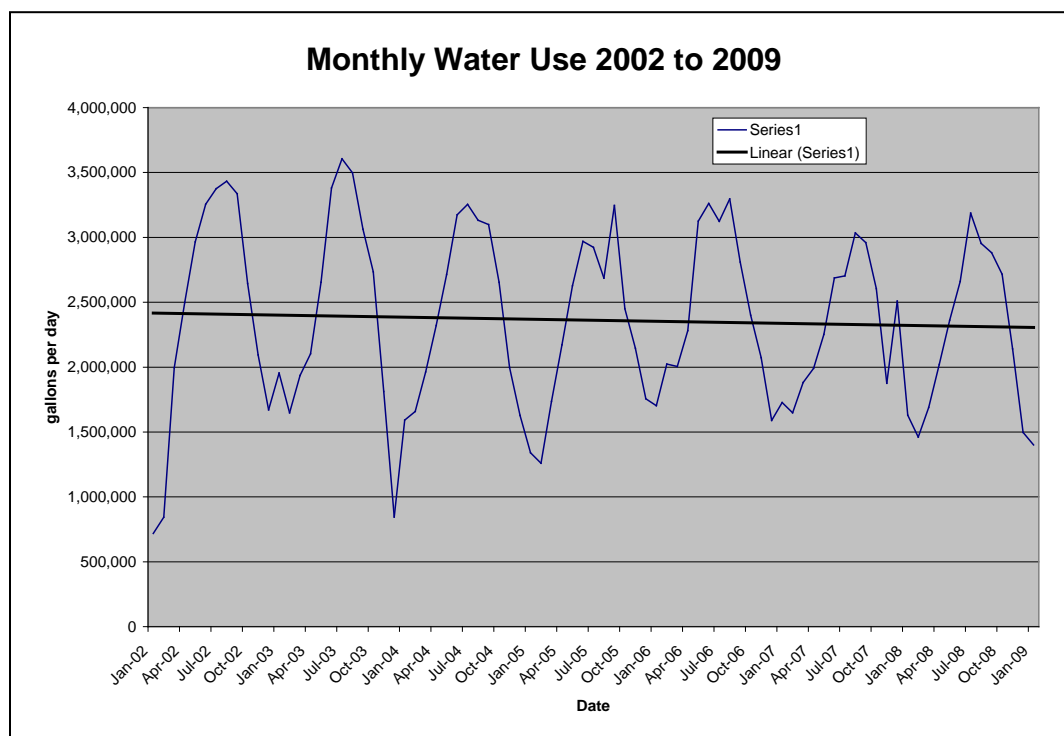
### **Historic water demand**

Fort Irwin began pumping groundwater in 1941. As the base grew over the following decades, new sources were used. Pumping began in Bicycle Basin in 1967 and in Langford Basin in 1992. The base was temporarily deactivated from 1972 to 1981 (Figure 39). By 1993 water demand rose to 2800 acre feet per year or 2.5 MGD. Demand trends over the past decade show an average daily demand of 2.4 MGD in 2000. This gradually declined to a demand of around 2.3 MGD as recently as 2009 (Figure 40). The recent decline has been attributed to reduction in irrigation due to increased xeriscaping within the cantonment area. Current water drawn from each basin is approximately 0.7 MGD, 0.8 MGD, and 0.8 MGD for Irwin, Bicycle, and Langford Basins, respectively (Woodruff 2010).



Source: Densmore 1997

Figure 39. Water pumping for Irwin, Bicycle, and Langford Basins, 1941-1993.



Source: Woodruff 2010.

Figure 40. Monthly trends in water use, Jun 2002 to Jan 2009.

## Developing the Fort Irwin regional model

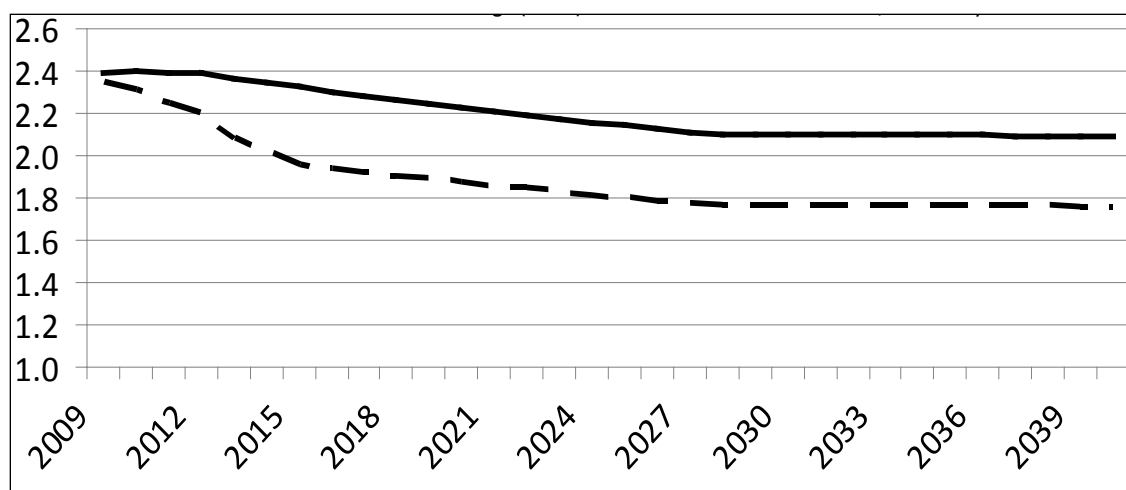
### Fort Irwin demand model

Fort Irwin's residential population is expected to remain relatively static in coming years, with a loss of 500 military and an increase of 340 civilian employees. However, construction of 187 new housing units will continue over the next few years. Despite having meters located throughout the housing units and on several administrative buildings, the consumption estimate of 1.2 MGD is based on square-footage rather than metered data. Monthly data are available for some of the irrigation and for the installation's total water use. Potential decreases in demand through reduced irrigation and expanded aboveground use of tertiary water were calculated, taking into account current demand, planned housing construction, and forecast increase in use of treated wastewater. If the water conservation requirements of E.O. 13514 are not implemented, overall water use is expected to increase slightly to 2.4 MGD until 2011 and to begin to decrease to approximately 2.1 MGD by 2040. Water consumption could drop to 1.76 MGD if Fort Irwin meets the annual water use reductions of E.O. 13514 (Figure 41).

### Water demand factors

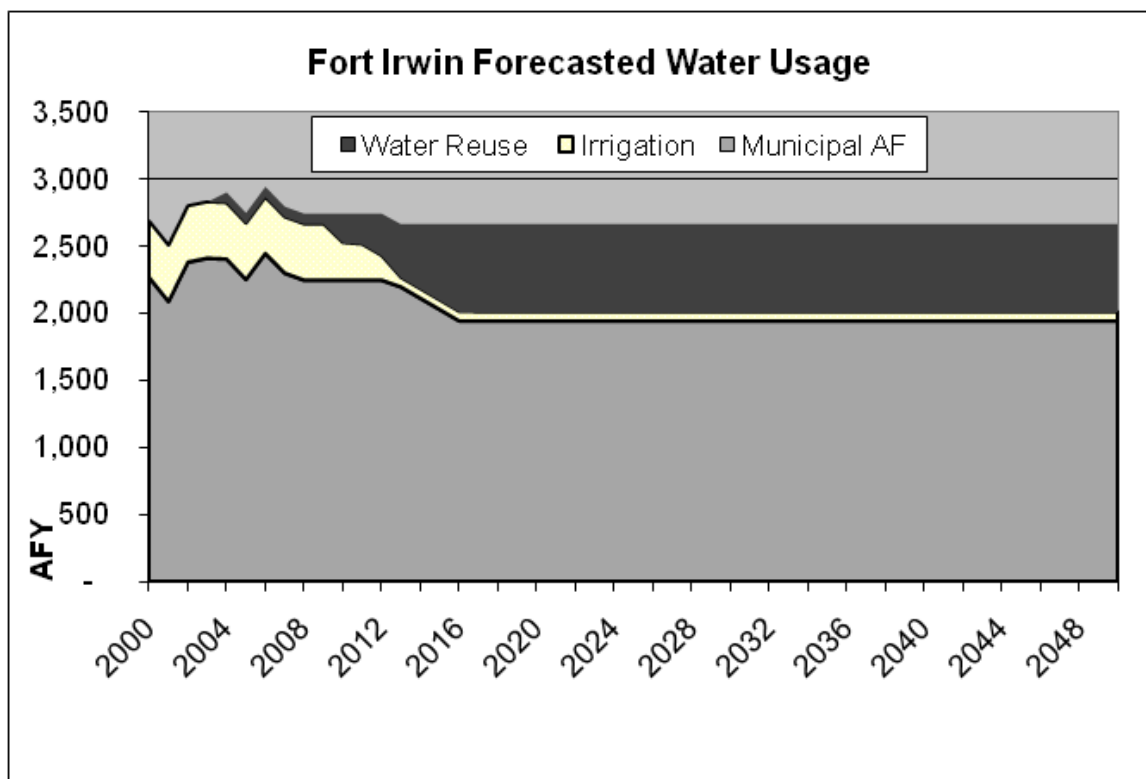
#### *Irrigation and Wastewater Treatment*

CH2MHill provided monthly irrigation, wastewater treatment, and pump specific production numbers to assist with determining consumption estimates. Data from Valleycrest, the other landscape irrigator, were unavailable. It was estimated from their general approximation of 0.4 MGD and 136 MG per year that CH2MHill provided 0.2 MGD towards irrigation on Fort Irwin. Beginning in 2011, water use permits will allow 71 MGY of treated wastewater to be used in place of fresh water for irrigation. By 2013, 0.29 MGD of treated wastewater will go toward irrigation at Fort Irwin. A wastewater treatment capacity of 0.58 MGD is expected to be reached by 2016. The additional treated wastewater is intended for other above ground consumption in the hope that use of treated wastewater will reduce overall consumption of potable water by a proportionate amount (Figure 42). Reduction in overall irrigation is not currently planned (Woo-druff 2010).



Source: Woodward 2009.

Figure 41. Fort Irwin Future Water Demand to 2040.



Source: Monthly water data and estimated treated wastewater (CH2MHill 2010; Woodruff 2009).

Figure 42. Fort Irwin water use.

### *Housing/Barracks*

Fort Irwin will have 2522 housing units after an additional 187 planned units are constructed. Barracks numbers are expected to remain the same. Although individual meters are installed in much of the existing housing, manpower restrictions prevent meter reading to determine actual consumption. Housing water consumption is estimated by using square foot-

age. It is equivalent to 54 percent of overall consumption or approximately 1.3 MGD. This equals approximately 89 gallons per capita per day (gpcd) when housing and barracks consumption are combined (Woodruff 2010).

#### *Rotational Units*

The National Training Center (NTC) at Fort Irwin is used to train military units for overseas deployments. The installation regularly hosts 10 to 12 rotations of units averaging around 5200 soldiers in each rotation. Much of the training for the rotational Soldiers is conducted at RUBAs outside the cantonment area. Water consumption for the training is unknown and can only be estimated at 0.31 to 0.41 MGD. Water supply contractors who directly support the training are not metered. Soldiers on rotation are not briefed on Fort Irwin's water limitations and it is unlikely that water conservation is practiced at the RUBAs.

Contractors provide and maintain water facilities for food services, laundry, and showers. Food preparation and shower facilities use open faucet fixtures. (Figures 43 and 44).

#### **Fort Irwin supply model**

Fort Irwin obtains all of its water from groundwater. The post's remote location restricts off-post impacts on Irwin's current water sources and supply. However, if Fort Irwin decides to obtain additional groundwater from Coyote Basin, legal issues and population forecasts described above may preclude the use of this groundwater source.



Figure 43. Typical shower units with pump station and water storage units.



Figure 44. Typical open air wash stations with push-button fixtures.

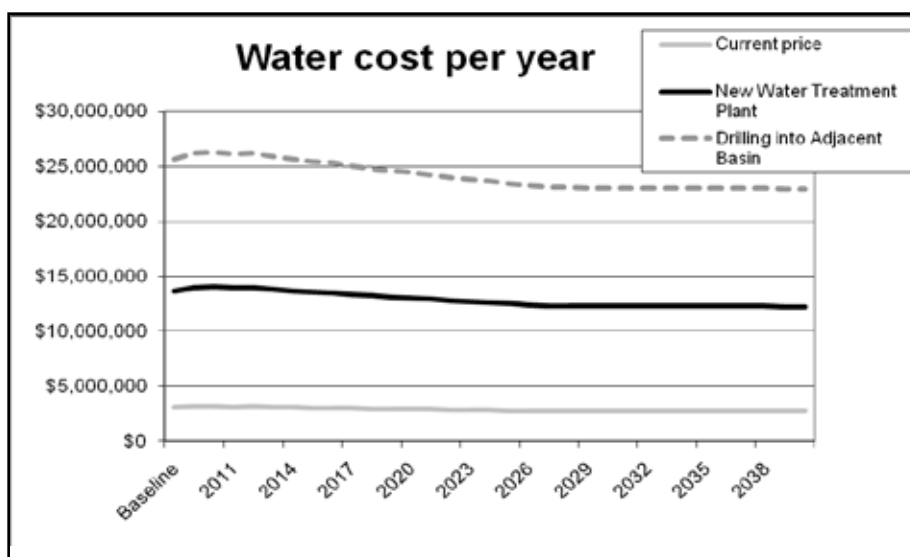
Figure 45 shows future comparative pricing based on current and projected future consumption. The current government water use rate per 1000 gallons is \$3.58, approximately \$3 million annually. If water management practices continue as expected, water use and the associated cost will decline (Kassab 2010). DPW staff estimate that the cost of water will rise to \$16 per 1000 gal when the new water treatment plant is brought on-line, increasing annual costs to about \$14 million. By 2040, Fort Irwin will spend \$12.5 million on water (Woodruff 2010). The third pricing scenario estimates an additional jump to \$30 per 1000 gal if Irwin were to pump water over the mountain range from an adjacent basin. This price scenario would increase annual costs to approximately \$26.5 million before decreasing to approximately \$23 million per year with current water demand management plans.

#### *Water sources and supply*

##### Fort Irwin Basin

Fort Irwin's initial groundwater source is located beneath the cantonment area. It is also the main point where groundwater recharge from wastewater and irrigation takes place within the cantonment area. Over time, water withdrawal shifted from Fort Irwin Basin to Bicycle and Langford Basins in order to meet demand. At the time of this study, 0.7 MGD of water is being drawn from Irwin Basin. Artificial recharge is estimated to be between 50 to 85 percent of the 1.1 MGD of treated wastewater produced. Subtracting wastewater used for Putt-Putt golf and then applying the higher rate (85 percent), 0.816 MGD of the treated wastewater is estimated to be percolating back into the soil, in addition to the 0.44 MGD of water used for irrigation. Calculated in this manner, Fort Irwin Basin storage is increased by 0.53 MGD through recharge (Figure 46).

Water withdrawals from Fort Irwin Basin will likely increase in the future in order to offset the declining water tables of the Bicycle and Langford Valley Basins. This will also prevent Fort Irwin Basin's now rising water table from reaching the surface (CH2MHill 2007). This assumption is reflected in the long-term basin demand scenarios. Recharge to the Fort Irwin basin comes from precipitation and artificial recharge from treated wastewater and irrigation. Precipitation is estimated to be about 50 acre-ft per year and is considered almost negligible for future supply because wastewater and irrigation percolation into the water table are the largest sources of groundwater recharge within the Fort Irwin Basin (Densmore 2003).



Source: Woodruff 2009.

Figure 45. Annual Water Cost Scenarios based on future water consumption.

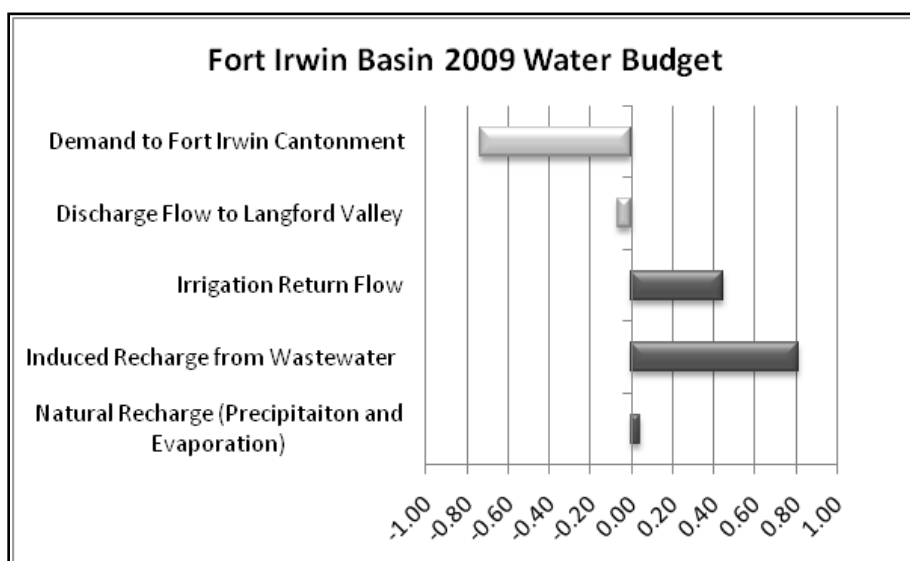


Figure 46. Fort Irwin basin water budget for 2009 (calculated).

“Although water levels are currently recovering in the Irwin Basin, percolating treated wastewater through evaporite deposits underlying the wastewater-disposal areas has resulted in high concentrations of dissolved solids in groundwater that is migrating toward the pumping depression (well bore) near the center of the basin” (Densmore 2003). This degradation in water quality is another factor that may limit water supply to the installation. Fort Irwin has recently fielded a new wastewater tertiary water treatment plant that is expected to save 300,000 gpd. This new plant puts sewage water through three levels of filtration, leaving the water clean enough to be used recreationally (Hong 2010). CH2MHill estimates that



the usable water storage in Fort Irwin Basin is anywhere from 40,000 to 70,000 acre feet. This calculates to be from 10 to 30 years at current use rates.

#### Bicycle Basin

Fort Irwin began pumping from Bicycle Basin, located to the northeast of the cantonment area, in 1967. Based on 2008 data, the installation uses an average of 0.78 MGD of water from Bicycle Basin. This withdrawal rate has caused subsidence of up to 12 ft in some areas and has begun to affect training operations above the basin (CH2MHill 2007). Some of the subsidence has been severe enough to cause cracks in the airfield located on the dry lake bed within the basin. At the time of this study, Well #5, thought to be the source of subsidence, has been shut down while the USGS studies the problem; they hope to determine possible solutions in order to increase the rate of recharge to the basin as a deterrent to further subsidence (Densmore 2010). Recharge to Bicycle Basin is mainly from infiltration of rainfall and percolation of runoff through ephemeral stream channels and is estimated to be approximately 0.03 MGD (Bader 1969; California Department of Water Resources DWR 1964). CH2MHill's (2007) current usable water storage estimate for Bicycle Basin is 30,000 to 100,000 acre feet, with an estimated 10 to 40 year supply.

#### Langford Valley Basin

Located to the southeast of Fort Irwin's cantonment area, Langford Valley Basin is forecast to have the largest potential water reserve of all basins currently in use. The available water supply is estimated to be 20,000 to 100,000 acre feet. Demand from Langford Basin is 0.76 MGD and natural recharge is estimated to be 0.04 MGD from precipitation and 0.07 MGD from inter-basin transfer from Fort Irwin Basin (Densmore 1997). Langford Valley Basin has also experienced subsidence, but not to the extent that it has affected training. The expected supply is estimated to last from 10 to 40 years. The 10 year estimated length of supply is used in the following to plan for earlier conflicts rather than later. Recharge to the basin is mainly from percolation of runoff through alluvial fan deposits at the base of surrounding mountains (California Department of Water Resources 1964, US Geological Survey 1986).

#### *Water supply factors*

The following analysis focuses on the long-term supply —out to 2040— provided by the three current supply basins and consideration of a new

source of supply. The baseline is set at 2008 because that is the most recent year for which comprehensive data are available. Withdrawals from the basins are compared with potential recharge factors such as waste percolation, precipitation, and underground water transfers. The water balance is analyzed by basin and includes the Fort Irwin, Bicycle, Langford Valley, and Coyote Lake Basins. Artificial recharge volume includes estimated wastewater percolation from treatment plant and irrigation.

The seven planning scenarios are based on current challenges facing Fort Irwin and issues that could affect water management decisions. Each scenario focuses on water demand and supply for the Fort Irwin region out to 2040. These scenarios are based on factors such as climate change, use of water from additional basins, change in artificial recharge, and water efficiency practices. Scenarios based on existing water supply variables involve varying demand and supply factors for the installation, including potential climate change effects (Table 24).

Projected change in precipitation due to climate change was derived from the 2009 California Climate Adaptation Strategy Discussion Draft provided by the California Natural Resource Agency (2009). Precipitation in California is expected to decrease by 12 to 35 percent. Due to the aridity and temperature extremes of the Mojave region, a 15 percent reduction was used for the moderate climate change scenario (Scenario 1) and a 35 percent reduction for extreme climate change scenarios. The next section covers each factor and how it varies in each scenario.

#### Fort Irwin Basin

Due to the severity of water scarcity at Fort Irwin and limited precipitation in the region, management of wastewater and irrigation recharge is of considerable concern. With artificial recharge outpacing withdrawal, the basin's water table is gradually rising in areas directly beneath the wastewater plant. These areas include major irrigation sites such as sports fields and putt-putt golf. An additional well may be added in this basin, but whether or not it is, all scenarios assume that additional pumping will occur in the Fort Irwin Basin. In addition, there will be an estimated 30 percent increase in basin demand by 2040. Scenarios 4 and 5 assume total recharge is reduced from 1.26 MGD to 0.93 MGD. Scenario 4 simulates increased water efficiency resulting in lower overall withdrawal, wastewater production, and irrigation. Scenario 5 simulates increased groundwater use either through additional pumping or additional reuse with unchanged rates of demand from the basins.

Table 24. Fort Irwin scenarios and factors.

Scenarios						Factors
1	2	3	4	5	6	
Fort Irwin Basin						
2%	2%	2%	2%	2%	2%	Percent of reduction
-15%	0%	-15%	-15%	-15%	-35%	Change in Natural Recharge
5%	5%	5%	5%	5%	5%	Change in recharge from basin trans fers
30%	30%	30%	30%	30%	30%	Change in pumping in Irwin Basin
15.0%	0.0%	15.0%	15.0%	15.0%	30.0%	Change in demand based on higher temperatures
1.3	1.3	1.3	1.3	1.3	1.3	Volume of artificial recharge
2005	2005	2005	2009	2005	2005	Year artificial recharge implemented
1.3	1.3	1.3	0.8	0.9	1.3	Volume of artificial recharge
2015	2015	2015	2015	2015	2015	Year artificial recharge implemented
Bicycle Basin						
2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	Percent of reduction
-15.0%	0.0%	-15.0%	-15.0%	-15.0%	-35.0%	Change in natural recharge
15.0%	0.0%	15.0%	15.0%	15.0%	30.0%	Change in demand based on higher temperatures
-15.0%	-15.0%	-15.0%	-15.0%	-15.0%	-15.0%	Change in pumping in Bicycle Basin due to subsidence
Langford Lake Basin						
2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	Percent of reduction
15%	0%	15%	15%	15%	30%	Change in demand based on higher temperatures
-15%	0%	-15%	-15%	-15%	-35%	Change in Natural Recharge
6%	6%	6%	6%	0%	0%	Percentage of groundwater recharge from Fort Irwin Basin
Coyote Lake Basin						
		2.0%				Percent of Reduction
		20%				Change in demand based on popula- tion growth by 2050
		15%				Change in demand based on higher temperatures
		-15%				Change in natural recharge

A 5 percent increase in basin transfers from Fort Irwin to Langford Valley is estimated, due to surplus groundwater as the result of artificial recharge. This is conditioned on an increase in pumping from Fort Irwin Basin of 30 percent.

#### Bicycle Basin

Due to water scarcity, each scenario assumes continued pumping from Bicycle Basin despite ongoing subsidence. USGS researchers are currently examining alternatives to facilitate the natural recharge of the basin and prevent further subsidence. No estimates are made regarding the effect of facilitated recharge on the amount of recharge available (Densmore 2010).

#### Langford Basin

These scenarios take into account the low range of supply estimates for each basin. Groundwater in the Langford Basin is estimated to last until sometime between 2022 and 2035 depending on extremes in climate change, increased water use, and inter-basin recharge rates. This contrasts with studies conducted by CH2MHill that project water supply in the Langford Basin may be depleted by 2035.

#### Coyote Lake Basin — Potential Future Source

Scenario 3 assumes that groundwater is withdrawn from Coyote Lake Basin beginning in 2032 as the Langford Valley Basin runs dry. As current water sources are depleted, it is expected that Coyote Basin might be explored to offset the loss of the Langford Valley Basin. Although Coyote Lake Basin is not currently in use (and is subject to legal barriers that may make its use difficult) it is the most likely new local source to supply Fort Irwin and the NTC. Estimates of groundwater availability range from 80,000 to 800,000 acre-feet. Scenario 3 assumes the low end of potential supply out to 2050. As part of the scenario, regional population growth and increased demand on the same basin is considered. Current demand is 0.96 MGD with expected regional population growth of 20 percent by 2050. Regional demand is expected to be 1.14 MGD by 2050. Due to the size of the basin, natural recharge is estimated at 0.43 MGD.

#### Climate Change

Temperature increases of up to 5 F are expected in the Mojave region surrounding Fort Irwin by 2050 and up to 9 F by 2100 (California Natural Resource Agency 2009). This will likely diminish the overall precipitation in the Mojave Region by 15 to 35 percent. It would also likely increase the overall demand for water for above ground uses in cooling and irrigation.

Scenarios include an increase in demand of 15 percent due to moderate climate change and up to 30 percent due to extreme climate. The increase in demand takes into account increased requirements for cooling, increased demand for irrigation, and increased water use by alternative energy strategies and carbon sequestration technologies. Scenarios 1, 3, 4, 5, and 7 assume moderate climate change. Scenario 2 assumes no climate change. Scenario 6 assumes extreme climate change.

#### Water Efficiency Practices

Water conservation extends the availability of existing water supplies compared to no conservation. Water reductions required by E.O. 13514 are factored into the reduction of water use in all but one scenario. Each scenario incorporates E.O. 13514 water conservation requirements except for Scenarios 4 and 7. Scenario 4 demonstrates water efficiency programs that go beyond E.O. 13514 (water efficiency policies that reduce consumption by 40 percent by 2016). Scenario 7 includes no conservation practices.

### **Fort Irwin 2040 water availability scenarios**

The data in Table 25 summarize all seven water availability scenarios for comparison.

#### **Scenario 1 – Moderate climate change**

Scenario 1 assumes that climate change yields a 15 percent decrease in precipitation and a 15 percent increase in overall demand by 2040. At the same time, wastewater percolation is expected to be offset by higher evapotranspiration rates, maintaining artificial recharge at approximately 1.26 MGD. By 2040, storage is expected to decrease to 19,746 MG from the 2008 baseline of 29,326 MG. The Langford Valley Basin could run out of available water by 2037 in this scenario's lower capacity estimates.

#### **Scenario 2 – No climate change**

Although projected climate change in California and the Mojave Desert region is significant, Scenario 2 assumes no climate change, in order to isolate the effects of changes in natural recharge on water availability at Fort Irwin. With no increase in demand or decrease in precipitation, it is estimated that there will be 21,757 MG stored in the three basins in 2040. Despite this increase in water availability, Langford Valley Basin is projected to be depleted of available water in or around 2039, 2 years later than projected in Scenario 1.

Table 25. Fort Irwin Water Management Scenarios

Fort Irwin Region	2008 Baseline	With E.O. 13514 integrated						7
		1	2	3	4	5	6	
		Moderate Clim Chg	No Climate Chg	Add- itional Basin	Water Efficiency	Reduced Recharge	Clim Chg Worst Case	No Conser- vation
Fort Irwin Basin	13,034	19,070	19,489	17,881	16,710	15,922	18,654	17,699
Bicycle Basin	9,776	1,302	2,416	1,302	4,209	1,302	206	237
Langford Lake Basin	6,517	-626	-148	-671	1,566	-1,237	-1,474	-1,472
Coyote Lake Basin	26,068			17,634				
Total Water Storage (MG)	55,395	19,746	21,757	36,147	22,485	15,987	17,387	16,464

**Scenario 3 — New basin**

Scenario 3 explores pumping from Coyote Lake Basin, assuming that withdrawal of water from the Langford Valley Basin will end in 2037. Since regional population is expected to grow, increased off-post demand from 0.96 MGD to 1.14 MGD by 2040 was projected. Using a lower-end availability estimate of 80,000 AF (26,068 MG), overall water availability for Fort Irwin would be 35,144 MG in 2040 down from 55,395 MG in 2008, the baseline year.

**Scenario 4 — Water efficiency**

Strict water management focusing on comprehensive water efficiency and irrigation reductions could result in a 40 percent decrease in overall water demand and recharge. Scenario 4 reflects this possibility, showing how efficiency measures can help alleviate climate change related increases in water demand. Guidelines by the Pacific Institute suggest a comprehensive water management plan could be integrated within 2 years. This scenario reflects an integrated efficiency program starting in 2016, resulting in remaining storage capacity by 2040 of 24,438 MG. Through water management, Langford Valley Basin, even at its lowest estimated capacity, could remain a viable source through 2040) and even to 2050 with a minimal 1,205 MG).

**Scenario 5 — Reduced recharge**

Reduced recharge without reduced water demand results in the lowest 2040 water availability. Langford Valley Basin may be depleted by 2032 because of lower artificial recharge due to increased above ground use of

wastewater. This scenario assumes that the limited inter-basin transfers stop due to the drop in the Fort Irwin water table. The reduced recharge scenario also reflects moderate climate change and corresponding increased water demand. By 2040, the estimated available water in all three basins is projected to be 14,946 MG, which is 51 percent of the 2008 baseline low-end availability.

#### **Scenario 6 — Climate change worst case**

Scenario 6 explores the worst case climate change scenario where temperature increase and precipitation decrease are extreme. A 35 percent decrease in precipitation and a 30 percent increase in water demand are estimated as a result of extreme temperature increase and increased evapotranspiration rates. This scenario assumes water management similar to that of Scenario 1. Results from Scenario 6 show only 16,372 MG will be available in 2040, down from the 18,202 MG expected for moderate climate change. Langford Valley Basin is projected to be depleted sometime around 2028, which indicates that increased demand and limited basin transfers may accelerate Langford Valley Basin's demise as a source of water.

#### **Scenario 7 — No conservation**

Scenario 7 assumes that none of the conservation requirements of E.O. 13514 are implemented. The result, assuming a moderate climate change, is that the available water supply in 2040 is expected to be around 16,646.

### **Water sustainability assessment for the Fort Irwin region**

Comprehensive water management and enforcement is the best case scenario in keeping long term costs down for both water and infrastructure investments. Limited precipitation due to moderate climate change is likely to lower the water volume stored in the basins by 9 percent, whereas extreme climate change has the potential to drop storage volume by 20 percent. Limiting recharge and not reducing demand, as in Scenario 5, has the most severe effect on future water availability with a comparative reduction of 26.4 percent in storage compared to Scenario 2. Acquiring water resources from Coyote Lake Valley would be the most reasonable option for increasing the water supply, except for two major issues: cost and legal restrictions by the Mojave Water Agency (CH2MHill 2007). These two issues may require that other more cost-effective strategies be considered. Scenario 4's comprehensive water efficiency program, which extends

beyond E.O. 13514 requirements, is the most ideal choice, but implementation, long-term funding, and enforcement will be challenging.

Column 7 of Table 25 also shows the overall difference between scenarios of moderate climate change with no integration of E.O. 13514 requirements. If the \$16 expected price increase was applied to these water amounts, \$52.5 million would be saved over the next 30 years by implementing E.O. 13514 requirements. If Fort Irwin were to go beyond those reductions and achieve a comprehensive 40 percent reduction in water demand, then \$96.3 million could be saved through 2040. Investments in a comprehensive water management program are also appealing in that the infrastructure costs would be even greater if Fort Irwin were to need an additional basin for supplying water to its cantonment area.

Increasing the funding of water management programs is critical for protecting the overall training mission. Without a comprehensive approach that includes participation of every major water user, including rotational units and contractors, the future costs of supplying water to Fort Irwin and its training will eventually overwhelm its budget.

### **Recommendations**

Recommendations for Fort Irwin to support water sustainability that can be adopted immediately include training and communicating the necessity of water efficiency and conservation to both garrison and rotational units. Landscape should be modified to limit or eliminate all but essential-to-training irrigation. Shower controls—for example push buttons or timers—should be installed in showering units for all training facilities.

Short term recommendations include prioritizing funding for water management programs. Further delay in implementing a conservation program will exacerbate water scarcity and impact base mission. Meters and an accountability system should be installed at water pump stations used by contractors and to supply the RUBAs. Identifying the water requirements of any alternative energy production project should be made an explicit criterion of these projects so that meeting energy targets does not become a water burden. Consideration should be given to the reuse of graywater in the RUBAs.

Long-term recommendations include installation-wide retrofit of water fixtures to high efficiency models. Water meters should be installed in buildings across the installation, including family housing, water stations,



and major users. New buildings should incorporate available and emerging concepts for water reuse in order to approach “net zero water.”

Fort Irwin staff is motivated to seek solutions to the region’s water scarcity challenge. At the time of this writing, several demonstration projects incorporating water-saving technologies at Irwin were in the planning stages. In addition, the US Geological Service received OACSIM funding to help support a Water Resources Study related to the planned regional solar energy project. Continued commitment to water sustainability will be necessary to support future viability of Fort Irwin and the National Training Center as the Army’s premier training center.

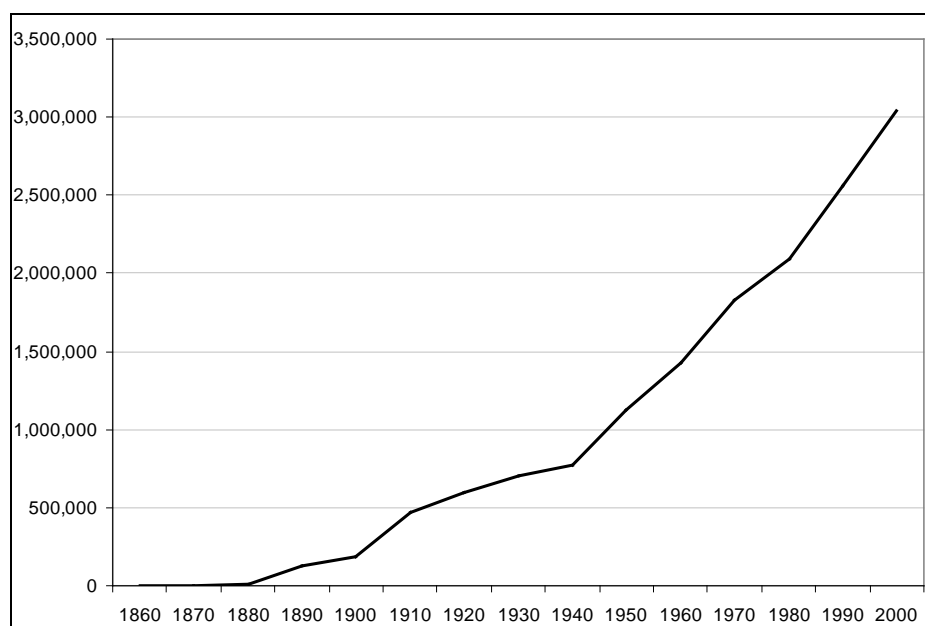
## **8 Joint Base Lewis-McChord, Washington**

In 1917, the citizens of Pierce County WA, spent \$2 million to buy 68,000 acres of land, which were donated to the Federal government for military use. The citizens' only stipulation was that the land be used as a permanent Army installation. Camp Lewis, named for Meriwether Lewis, was established. Later, Camp Lewis became Fort Lewis. In 1938, construction began on an adjoining Army airfield, which later became McChord Air Force Base. In February 2010, Fort Lewis and McChord Air Force Base combined under the 2005 Base Realignment and Closure process to form Joint Base Lewis-McChord (JBLM).

This chapter focuses on the JBLM-Cantonment potable water system only, formerly the drinking water system for Fort Lewis, although there are four other drinking water systems present on the installation. The JBLM-Cantonment drinking water system supplies drinking water to JBLM Main and JBLM North areas.

Today, JBLM encompasses nearly 90,000 acres and is one of only 12 joint base power projection platforms worldwide. Primary force-projection components of JBLM are I Corps and the 62nd Airlift Wing. Additional tenants include, the 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> Stryker Brigade Combat Teams; the 2<sup>nd</sup> Infantry Division; 593<sup>rd</sup> Sustainment Brigade; the 555<sup>th</sup> Engineer Brigade; the 17<sup>th</sup> Fires Brigade; the 42<sup>nd</sup> MP Brigade; the 62<sup>nd</sup> Medical Brigade; the 201<sup>st</sup> Battlefield Surveillance Brigade; Western Region Cadet Command; 1<sup>st</sup> Special Forces Group (Airborne), 2<sup>nd</sup> Battalion, 75<sup>th</sup> Ranger Regiment; Madigan Army Medical Center; and US Army Garrison, Fort Lewis. The installation's population is expected to exceed 35,000 soldiers and civilian workers by 2013 (Fort Lewis website 2009, Gibbens 2010).

JBLM, which is situated about 35 mi south of Seattle, is part of the Seattle-Tacoma-Bellevue, Washington, Metropolitan Statistical Area (MSA). In 2008, the MSA was home to over 3.3 million people (US Census Bureau 2010). The metropolitan area has seen rapid population growth since the 1940s (Figure 47). By 2030, the MSA is projected to have a population of almost 5 million (Washington Office of Financial Management 2009).



Source: Washington Office of Financial Management 2009.

Figure 47. Population growth in the Seattle-Tacoma-Bellevue MSA (1860-2000).

This study analyzes potential future water availability through use of a regional water balance and suggests policies that may aid in maintaining a sustainable water supply in this growing region.

## Regional characterization of Joint Base Lewis-McChord

The following section describes the natural and human systems that define the JBLM region and that influence development and outcomes of the regional water balance.

### Demographic trends

JBLM is located on the southern edge of the Seattle urbanized area between Tacoma and Olympia, the state Capitol (Figure 48). The Seattle-Tacoma area has long been recognized as the major economic and cultural center of the Pacific Northwest. Native Americans lived in the area for thousands of years when European settlers first arrived in Seattle and Tacoma in the mid-1800s (Sale 1976).

JBLM spans two counties, Pierce and Thurston. The first Federal decennial census to include these counties was in 1860 and listed 1115 residents in Pierce and 1507 residents in Thurston. In 2008, these counties had populations of 785,639 and 245,181, respectively (Washington Office of Financial Management 2009). Figure 49 shows the long-term population trends in these counties.

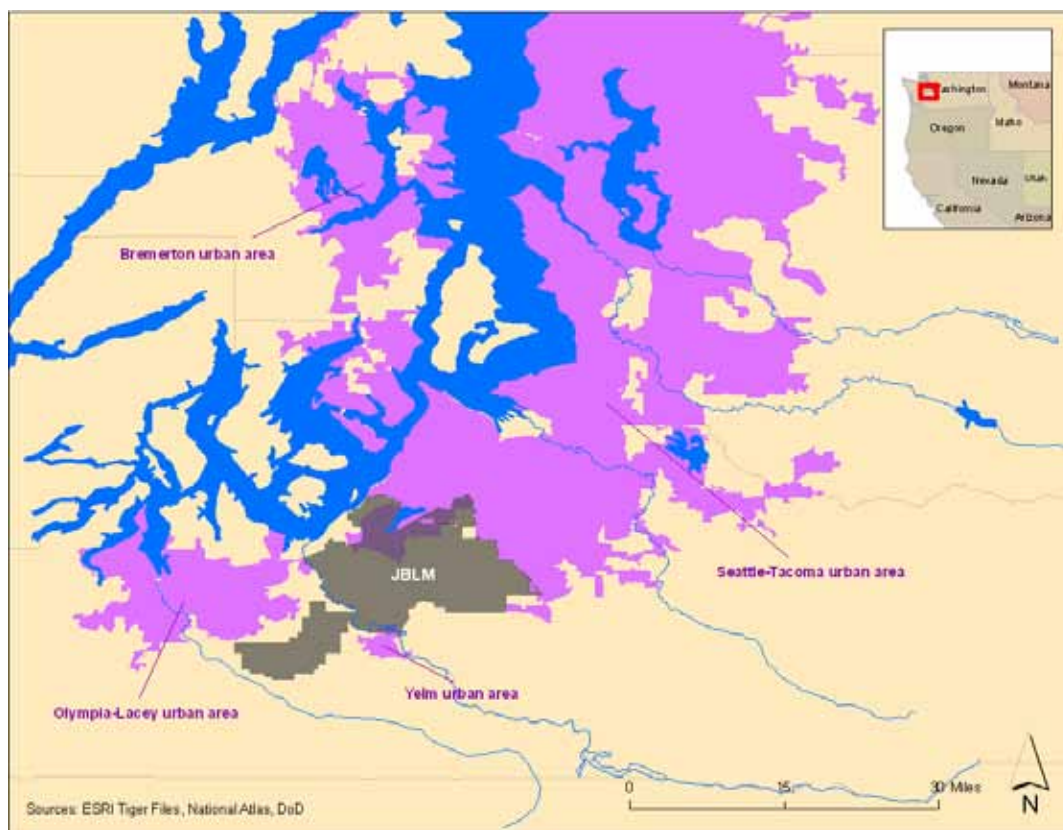
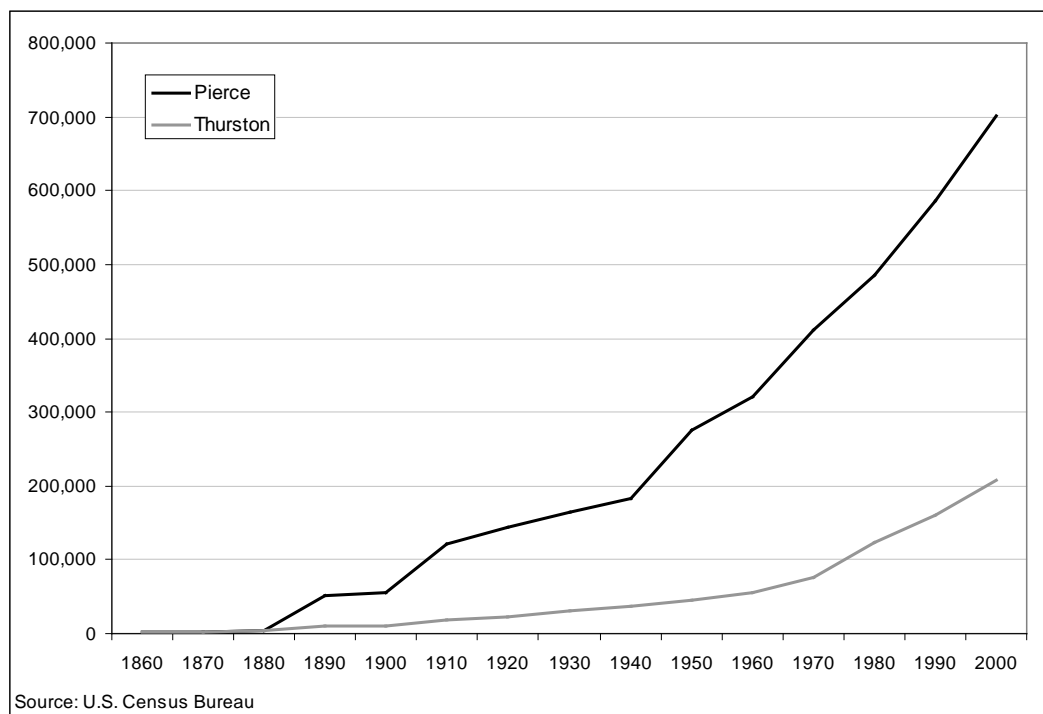


Figure 48. Location of Joint Base Lewis-McChord in the Seattle-Tacoma area.



Source: Washington Office of Financial Management 2009.

Figure 49. Historic population growth in Pierce and Thurston counties.

The Seattle-Tacoma-Bellevue MSA, which includes King, Snohomish, and Pierce counties, is currently the 15<sup>th</sup> most populous MSA in the nation with over 3.3 million residents. It is also the largest metropolitan area in the state of Washington and in the Pacific Northwest. Out of the nation's 20 largest MSAs, Seattle-Tacoma-Bellevue ranked 12<sup>th</sup> in percent growth between 2000 and 2003. By 2030, the metropolitan population is projected to reach almost 4.9 million, an increase of 48 percent over the 2008 population. This population growth will likely require the development of additional potable water sources to meet the expected demand.

JBLM is also located within the Seattle-Tacoma-Olympia combined statistical area (CSA). The CSA is based on commuting patterns and is currently the 13<sup>th</sup> most populous in the U.S with almost 4.1 million people. The CSA includes King, Snohomish, Pierce, Thurston, Kitsap, Skagit, Island, and Mason counties (US Census Bureau 2010). The Washington Office of Financial Management, which provides the state's official population projections, projects that the CSA's population will reach 6.1 million by 2030.

### **Regional definition**

The study region is the sub-basin of the Puget Sound watershed in which all of JBLM's wells and its spring source are located. This region was chosen because it is the recharge area for the aquifers that provide JBLM's water supply and is located entirely within Pierce County. Most of the study area is located within the JBLM cantonment and the Tacoma urbanized area (Figure 50).

Although they are not in the relatively small study region, it is important to keep the rest of Pierce, King, and Thurston counties in mind when analyzing water supply and demand issues in the JBLM region. Both Pierce and King Counties rely mostly on surface water to meet their potable water needs, but both have been increasing their groundwater withdrawals substantially in recent years. Hydraulic connectivity between the aquifers in the Puget Sound regional aquifer system is unknown — this is discussed in the following section — so it is difficult to determine the effects on JBLM's water supply of increased groundwater withdrawals in other parts of the Seattle-Tacoma-Olympia area.

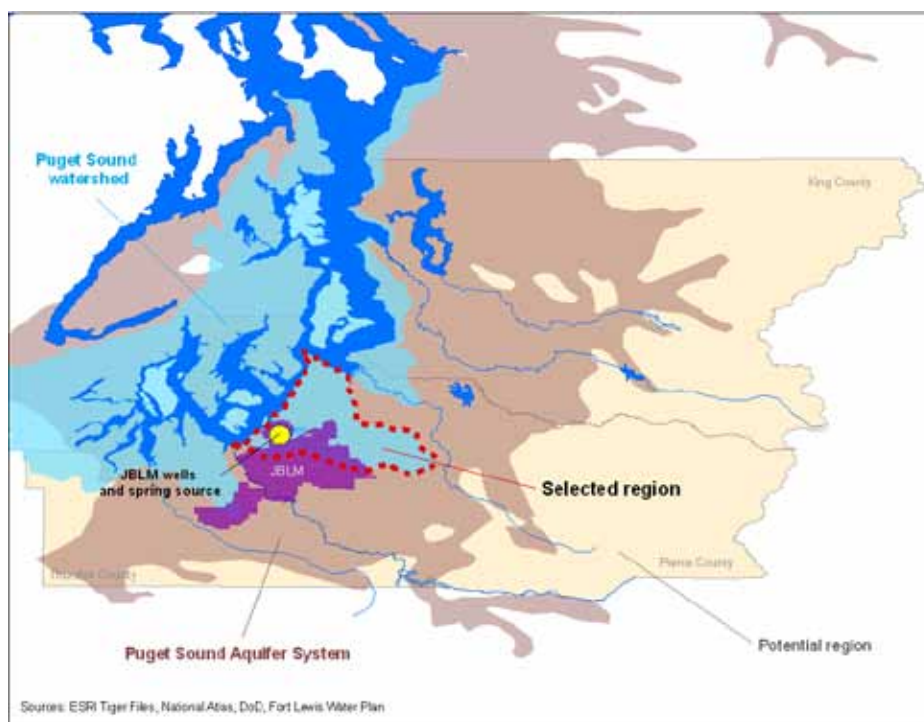


Figure 50. Joint Base Lewis-McChord regional definition map.

### Water sources

Water availability has been and is currently the major long-term water issue in the state of Washington (Whitehead 1994). Meeting the water needs of people and fish habitats in the central Puget Sound area with available resources is becoming increasingly difficult (Central Puget Sound Water Suppliers Forum 2001). The study region relies primarily on spring sources, groundwater withdrawn from the Puget-Willamette Trough regional aquifer system, and surface water from the Green River.

The Puget-Willamette Trough regional aquifer system is a complex, heterogeneous aquifer located underneath an elongated basin that stretches from the Canada/Washington border to central Oregon. The basin consists of three areas: the Puget Sound lowland in northern Washington, a central area from the Puget Sound lowland to northern Oregon, and the Willamette River Valley in central Oregon. JBLM is located in the Puget Sound lowland area.

The regional groundwater system consists of aquifers and aquitards, which are strata composed of silt and clays that usually do not produce significant quantities of groundwater (Fort Lewis Directorate of Public Works 2008). The aquifers are mostly unconsolidated-deposit aquifers, formed by glacial deposits up to 3000 ft thick. The upper 200 to 300 ft are gener-

ally made up of sand and gravel deposits and contain the most productive aquifers, which often produce more than 2000 gpm. Some wells in the Seattle area have even yielded up to 10,000 gpm.

Four effective aquifers are located underneath JBLM. From shallowest to deepest, they include the Vashon Drift aquifer, the sea level/Salmon Springs aquifer, and two unnamed aquifers about 300 and 800 ft below the land surface, respectively (Fort Lewis Directorate of Public Works 2005). The Vashon Drift aquifer, also referred to as the “upper” aquifer, is made up of several mostly continuous aquifer-type units and discontinuous confining-type units (Dinicola 2005).

The Vashon Drift aquifer is the source of water for Sequim Springs and two of JBLM’s primary supply wells, wells 12A and 12B. It is on average ~80 ft deep and is recharged mostly through precipitation infiltration.

The Salmon Springs aquifer is part of the sea-level or “lower” aquifer, which consists of a complex, irregular layering of glacial drifts and non-glacial deposits, which act as confining units. This aquifer supplies two of JBLM’s wells, one primary supply well — well 14 — and one emergency well — well 13. The Salmon Springs aquifer is separated from the Vashon Drift aquifer by the fine-grained sediments of the Kitsap Formation, which act as aquitards. The Kitsap aquitard supplies three of JBLM’s wells, wells 6, 17, and 20, although only well 20 is a primary supply well. A lens in the Kitsap Formation, located near the Logistics Center, allows for recharge of the Salmon Springs aquifer. Two of JBLM’s wells are supplied by this aquifer. The neighboring city of DuPont also withdraws water from the Salmon Springs aquifer (City of DuPont 2009).

The two unnamed aquifers, considered “deeper” aquifers, are part of the Kitsap Formation and consist of coarse-grained sediments (Pierce County Department of Public Works and Utilities Water Programs Division 2001). The shallower of the two aquifers is separated from the Salmon Springs aquifer by the fine-grained sediments in the Puyallup Formation; no “windows” between the two have been identified. Little is known about the deeper of the two unnamed aquifers. Table 26 lists the JBLM wells and their groundwater sources and Figure 51 provides a generalized conceptual model of the hydrogeologic makeup of west-central Pierce County.\*

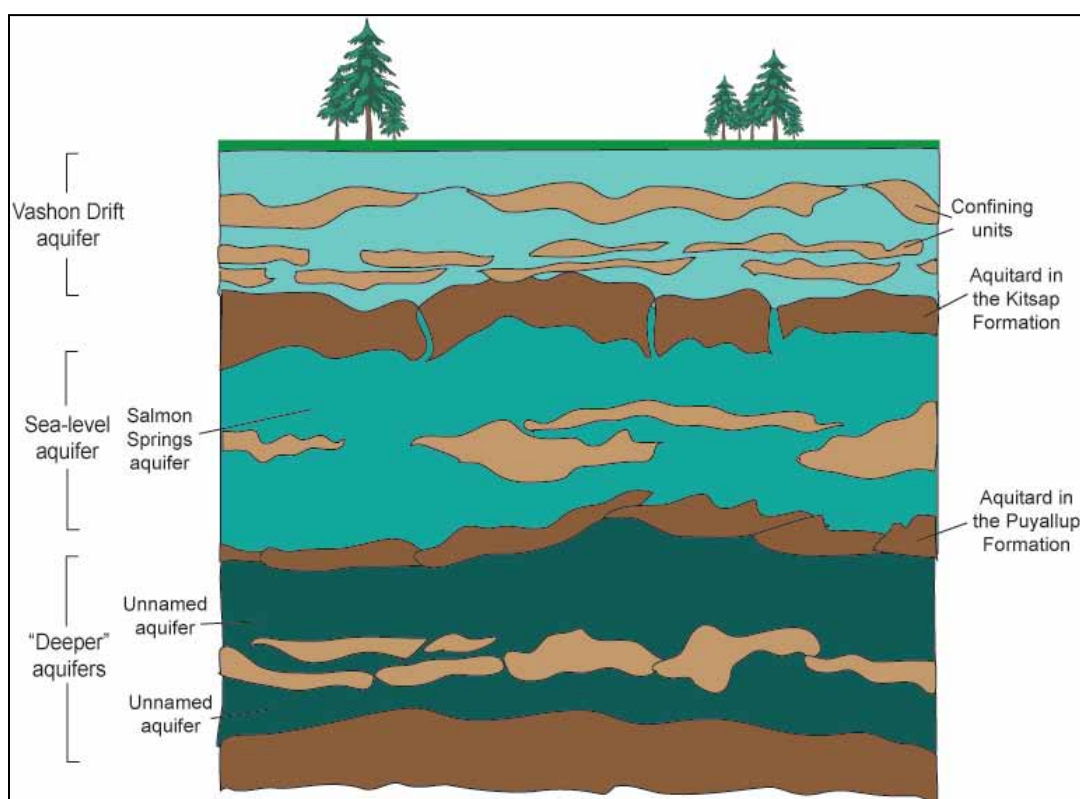
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\* Note that the image in Figure 51 is a conceptual representation of the hydrogeologic strata. The vertical scale is greatly exaggerated.

Table 26. JBLM wells and their sources of groundwater.

Well number	Depth (ft below land surface)	Capacity (gpm)	Source of supply	Notes
6	1353	400	Kitsap aquitard	To be decommissioned
13	275	1000	Salmon Springs aquifer	Emergency source only
14	354	1000	Salmon Springs aquifer	Primary well supply source
17	550	450	Kitsap aquitard	
20	700	1650	Kitsap aquitard	Primary well supply source
12A	17	1400	Vashon Drift aquifer	Primary well supply source
12B	17	1300	Vashon Drift aquifer	Primary well supply source

Source: Fort Lewis Directorate of Public Works 2007



Sources: Dinicola, 2005, Fort Lewis Directorate of Public Works 2007

Figure 51. Generalized hydrogeologic framework of the Joint Base Lewis-McChord area.

Wells only withdraw a small percentage of the water from the Puget Sound unconsolidated-deposit aquifers. Most of the available groundwater is discharged through springs. Some springs, like those fed by unconsolidated deposits of glacial-outwash gravel, can discharge up to 20,000 gpm (Whitehead 1994). Sequalitchew Springs, the largest single water source in the JBLM water system, can produce up to 9600 gpm. Sequalitchew Springs was originally classified as a surface water source, but it is now



considered a groundwater source due to the addition of a concrete cover to prevent contamination (Fort Lewis Directorate of Public Works 2005). McAllister Springs, which is located in Thurston County, produces up to 11,000 gpm (Whitehead 1994), providing 84 percent of Olympia's water supply (City of Olympia 2009). The city of Olympia has determined that McAllister Springs' water quality diminishes during periods of heavy demand, and is in the process of replacing this water source with high-capacity groundwater wells (Pacific Groundwater Group 2009).

The Green River, which provides most of Tacoma's water supply, is located in King County with headwaters in the Cascade Mountains. The river is 65 mi long and is called the Duwamish River for the lower 12 mi before it empties into Elliot Bay in Seattle (Figure 52). The city of Tacoma filed for water rights in the Green River shortly before World War I. Today much of the Green-Duwamish watershed is heavily restricted from public access. The river has two dams: the Tacoma Water Supply Diversion Dam, built in 1911, and the Howard Hanson Dam, built in 1962 (King County 2009). Tacoma Water, the city's water provider, has rights to withdraw up to 138 MGD from the Green River, provided minimum streamflows are met. In 2007, Tacoma Water conducted a water availability study. This study concluded that 2025 would be the most difficult year to meet water demand (Tacoma Water 2009).

#### **Joint Base Lewis-McChord water rights**

Washington State first established procedures for the appropriation of public waters in 1891, though since then the process has been altered several times. The Groundwater Code was adopted in 1945 and recognizes existing water rights that were established by the development and use of groundwater prior to June 6 of that year. Between 1969 and 1974, the Water Rights Restoration Act permitted all users to register groundwater rights if they had been established prior to the 1945 legislation.

Washington's Department of Ecology (DOE) is responsible for issuing all water rights in the state. However, as a military installation, JBLM has a Federally reserved water right for all of its present and future consumptive uses and is not required to file water rights claims with the state of Washington. JBLM currently holds water rights claims for Sequelitchew Springs and for eight of its 11 wells (Fort Lewis Directorate of Public Works 2005).

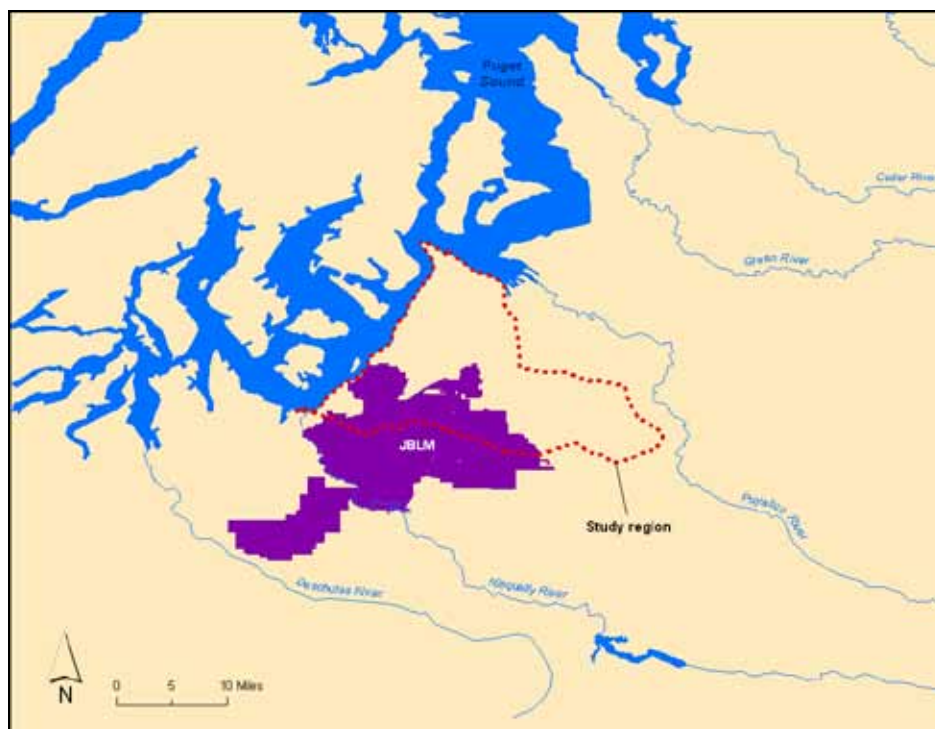


Figure 52. Major rivers in the Joint Base Lewis-McChord area.

## Climate

The JBLM area has a temperate marine climate with warm, dry summers and cool, wet winters. The coolest month is January, which has average high and low temperatures of 48 and 36 F. August is the warmest month with average high and low temperatures of 77 and 55 F. During the summer of 2009, however, the Seattle area saw record high temperatures (<http://www.beautifulseattle.com/mthsum.asp> 2010). Most of the 40 in. of average annual rainfall occurs between October and March. Snowfall is infrequent and rainfall is usually not intense (Dinicola 2005). The average annual streamflow at the Howard Hanson Dam gage site since 1960 has been just over 643 MGD, with the lowest annual average occurring in 1983 at just over 407 MGD.

## Topography

JBLM spans three watersheds — Puget Sound, Nisqually, and Deschutes — and lies at the southern end of the Puget Sound lowland, within the Chambers Creek and Nisqually River Basins (Fort Lewis Directorate of Public Works 2005). Bordered by Puget Sound to the northwest, JBLM is located on a gently rolling upland plain about 200 to 300 ft above sea level. More than 1000 ft of unconsolidated glacial and inter-glacial sediments lie underneath the area. Soils in the area are mostly coarse-grained glacial-

outwash derived soils that do not retain water and are very well drained (Dinicola 2005). The Cascade Mountain range to the east includes the 14,410 ft-tall volcano Mount Rainier. Although Mount Rainier has not erupted since 1895, it is considered one of the nation's most dangerous volcanoes. Surrounding areas, including JBLM at 40 mi away, are at a high risk of potentially deadly volcanic mudflows (Driedger and Scott 2008).

### **Land use**

The study region is mostly a developed, urbanized area. The city of Tacoma, its suburbs, and the JBLM cantonment area account for the vast majority of this urbanized area. Large evergreen forests are in the southern and western parts of the area. Small areas of pastures, hay, and deciduous forest also dot the study area (Figure 53 ).

### **Historic water demand**

In 2005, King, Pierce, and Thurston counties used a combined total of 56 percent surface water and 44 percent groundwater. Average daily withdrawals (surface and groundwater) for the three counties in 2005 were just over 470 MGD (Table 27).

Although they still obtain most of their water supply from surface water sources, rapidly-growing King and Pierce counties have been increasingly relying on groundwater. King County's groundwater withdrawals increased 79 percent from 1985 to 2005, while its surface water withdrawals decreased 16 percent. The continued growth of the Seattle-Tacoma area is likely to extend this trend as new residents increase the demand for water.

## **Developing the Joint Base Lewis-McChord regional model**

JBLM draws its own water from 11 wells and a spring source, Sequalitchew Springs, and 12 storage reservoirs that can collectively hold over 6 million gallons. As mentioned previously, the largest single water source in the JBLM system is Sequalitchew Springs, located on the installation near American Lake. Additionally, JBLM has three other potable water systems: the Golf Course, Ammunition Supply Point (ASP), and Range 17 systems, all of which are supplied by groundwater wells and supply minimal amounts of water compared to the main water system. Other users in the area that withdraw from the same aquifers as JBLM include the McChord Field drinking system and the city of DuPont.

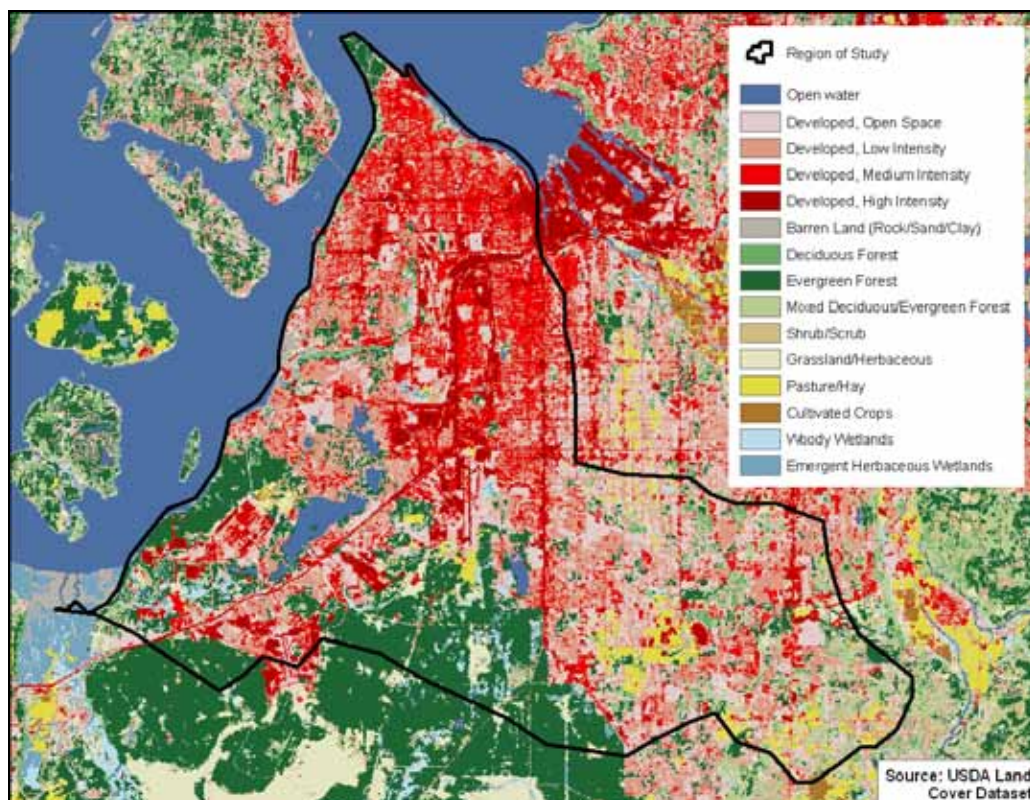


Figure 53. Land use in region of study.

Table 27. Historic water use in King, Pierce, and Thurston Counties.

		King	Pierce	Thurston	Total
Groundwater	1985	44.9	71.6	28.7	145.2
	1990	92.9	100.5	34.8	228.1
	1995	98.6	136.1	43.3	278.1
	2000	101.2	75.4	29.3	205.8
	2005	80.3	85.2	40.7	206.3
	Pct change 1985-2005	79%	19%	42%	42%
Surface water	1985	176.0	107.8	4.4	288.2
	1990	244.7	87.2	4.9	336.8
	1995	192.9	82.8	6.3	282.0
	2000	259.3	151.8	15.6	426.8
	2005	147.6	113.3	5.5	266.4
	Pct change 1985-2005	-16%	5%	25%	-8%
Total withdrawals	1985	220.9	179.3	33.1	433.4
	1990	337.6	187.6	39.7	565.0
	1995	291.6	218.9	49.6	560.1
	2000	360.5	227.2	44.9	632.5
	2005	227.9	198.5	46.2	472.6
	Pct change 1985-2005	3%	11%	40%	9%
Population pct change, 1985-2005		36%	50%	72%	42%
Source: USGS 2005.					

### **Water supply model**

The year 2005 is used as the model baseline and supply is projected under several alternate future scenarios out to 2040. The model is analyzed at the study region scale because it is unknown how the localized aquifers underlying JBLM are hydrologically connected to other regional aquifers.

#### *Aquifers in the JBLM region*

Past research has found that recharge rates for aquifers in the Puget Sound lowland, which front spring sources like Sequelitchew Springs, can vary widely depending on their location and hydraulic characteristics.

The estimated mean annual recharge for the undeveloped JBLM region is 23.75 in. per year, which corresponds to over 208 MGD when calculated for the 184 square mile drainage basin that forms the study region. However, most of the land cover in the study region is developed land covered by impermeable surfaces that do not allow water to percolate to the aquifers. Therefore, it was assumed that the actual permeable surface cover in the study area was about a third of the 184 sq mi, or about 61 sq mi. This translates into a more likely recharge volume of about 69 MGD.

#### *Drivers for water supply*

The main driver for water supply in the study region is the change in water volume stored in the aquifers that underlie the area. The change in storage includes recharge loss due to evapotranspiration, JBLM withdrawals, and the region's other groundwater withdrawals. The region's other groundwater withdrawals were calculated by assuming that 65 percent of Pierce County's population resides within the boundaries of the study area. JBLM's estimated 2005 withdrawals were subtracted from Pierce County's and the resulting number was multiplied by 0.65 to obtain the estimated groundwater withdrawal from the study area.

### **Regional water demand model**

The water demand projection for the JBLM region is based on the initial 2005 consumption and the population projections for the study region of. Since the state of Washington has not made official population projections for the years past 2030, a linear trend is assumed from 2030 to 2040. It is also assumed that total withdrawals will grow with the population at the same rates observed from 1985 to 2005.

### **JBLM water demand model**

The JBLM Water Demand Projection uses records of historical water use, real property, planned construction, and population projections for the installation to predict future water demand. Water use is predicted by category of building (family housing, industrial, storage). The installation does not meter water data by building at present. Building level water use factors, as compiled by Billings and Jones (2008), were used to predict the amount of water used per building — or in the case of barracks and family housing, per resident. Local evapotranspiration was also taken into account to help predict irrigation water demand.

Assuming — as this model does — that water use at JBLM decreases 2 percent every year until 2020 as mandated by E.O. 13514, water use is expected to peak at 5.07 MGD in 2011, then decrease to 3.96 MGD by 2020. The base's structures and population are expected to remain at roughly the same levels after 2013. This means that after 2020, the only changes in water usage from the installation will result from projected decreases in water loss in the distribution system. Current losses are estimated to be roughly 18 percent based on the Fort Lewis Water Plan (Fort Lewis Directorate of Public Works 2007). This is a relatively high number so this study assumes that installation staff will work to decrease water losses over the coming years until they reach the national average of 11 percent. JBLM total water demand in 2040 is expected to be 3.85 MGD (Figure 54).

### **Joint Base Lewis-McChord water demand model results**

Figure 55 shows the region's baseline projected total withdrawals. Consumption is projected to grow by about 0.5 percent per year in the JBLM region through 2040. This projection assumes a decrease in regional water use by 1 percent annually in gallons used per person per day in accordance with larger national trends of decreasing water use. The projection includes water use reductions on the installation of 2 percent per year each year until 2020 in compliance with E.O. 13514.

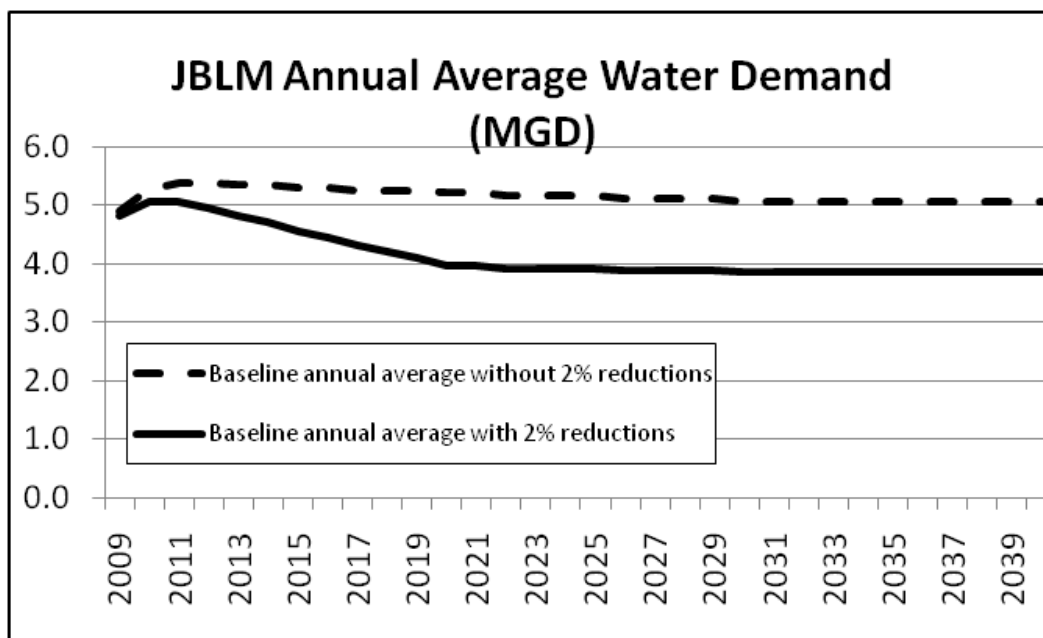


Figure 54. Joint Base Lewis-McChord water demand projections with and without water use reductions.

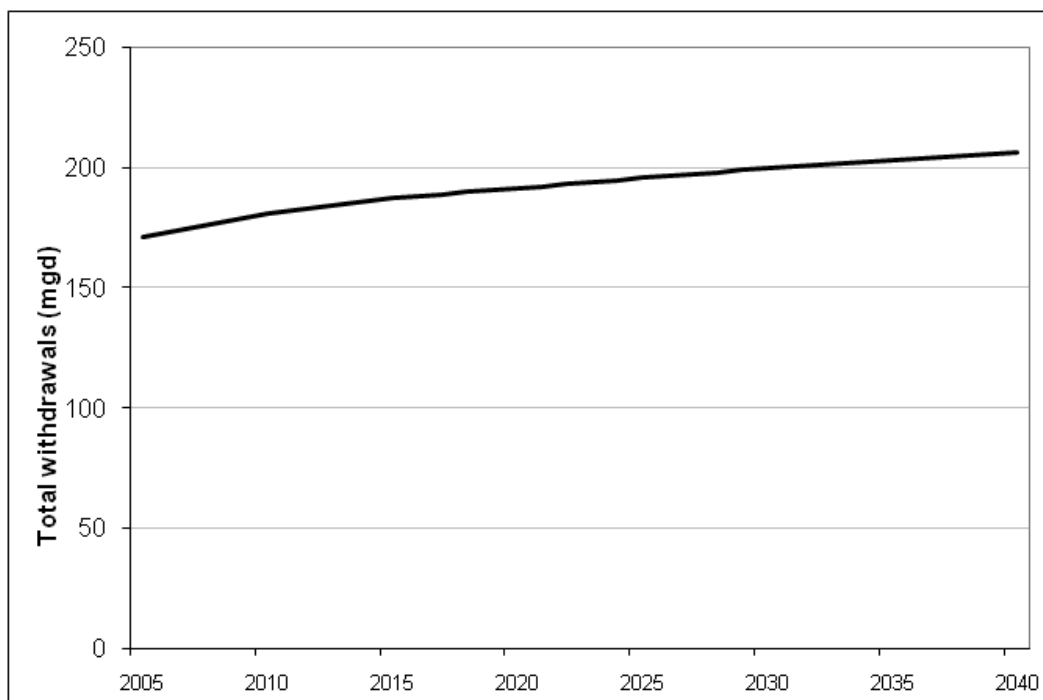


Figure 55. Demand projections for the Joint Base Lewis-McChord region.

## **Joint Base Lewis-McChord 2040 water availability scenarios**

### **Scenario 1 — Climate change**

The Pacific Northwest has grown warmer and wetter since the beginning of the 20<sup>th</sup> century. Annual precipitation has increased by 10 percent on average. Warm years tend to be relatively dry with low streamflow and light snowpack, whereas cool years are wetter with a high streamflow and heavy snowpack. The two primary models used to predict changes in climate for the US are the Hadley and the Canadian models. Both models project that 21<sup>st</sup> century climate change will be much more pronounced than it was in the 20<sup>th</sup> century. Both also project that average precipitation will increase, but that these increases will be concentrated in the winter. This means that increases in precipitation will not necessarily lead to an increase in available water supply, especially during dry summers. Both models also project increases in extreme precipitation events and a 5 F warming west of the Cascade Mountains (National Assessment Synthesis Team 2000).

Scenario 1 assumes that, in spite of projected increases in precipitation, aquifer recharge will actually decrease about 10 percent by 2040 because the area of the study region covered by impervious surfaces will increase (Figure 56). It also uses the baseline values for the change in JBLM withdrawals from the installation demand model, and the change in other regional groundwater withdrawals from the regional demand model.

### **Scenario 2 — Greatly increased demand**

Scenario 2 assumes an unexpectedly rapid increase in water demand for the region and a slower than expected decrease in water demand for the installation. This could be due to population growth or significantly increased regional industrial use. At the installation scale, this could be due to a mission change that results in more water use on the installation than previously expected. In this scenario, change in regional population between 2010 and 2040 is assumed to be 25 percent higher than currently projected resulting in a greater water demand. Baseline projections for the installation indicate that water demand will both increase and decrease over the 30-year period so increases were exaggerated by 25 percent and decreases were dampened by 25 percent. It is assumed that precipitation patterns will stay the same and aquifer recharge rates will only decrease by 5 percent (Figure 57)



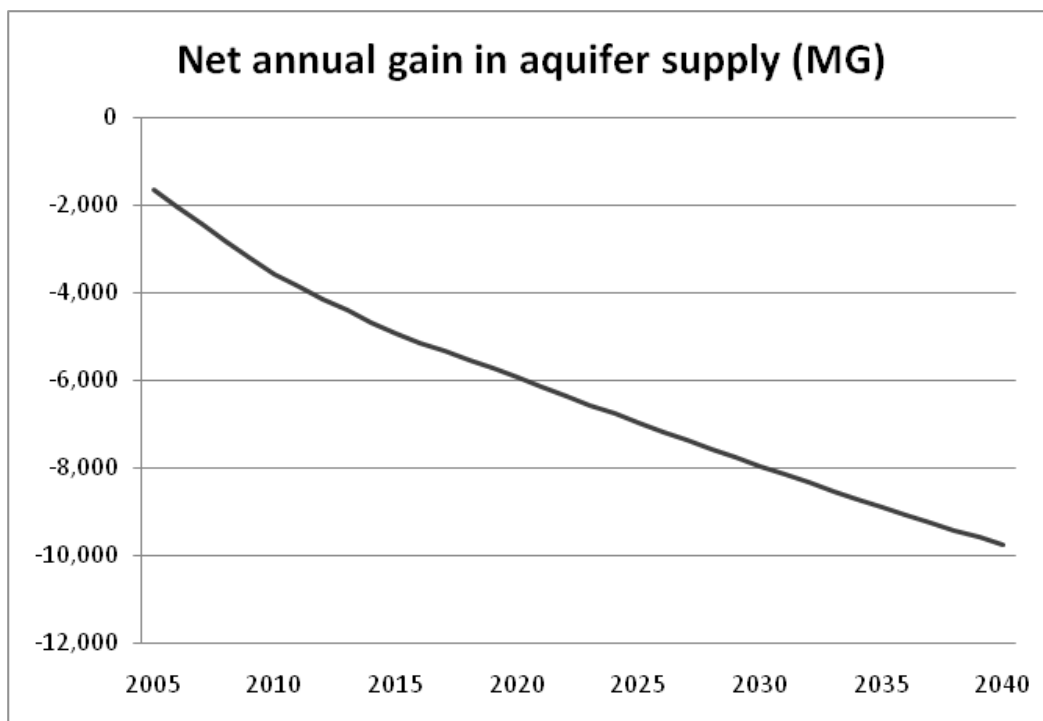


Figure 56. Scenario 1 results (Joint Base Lewis-McChord, WA).

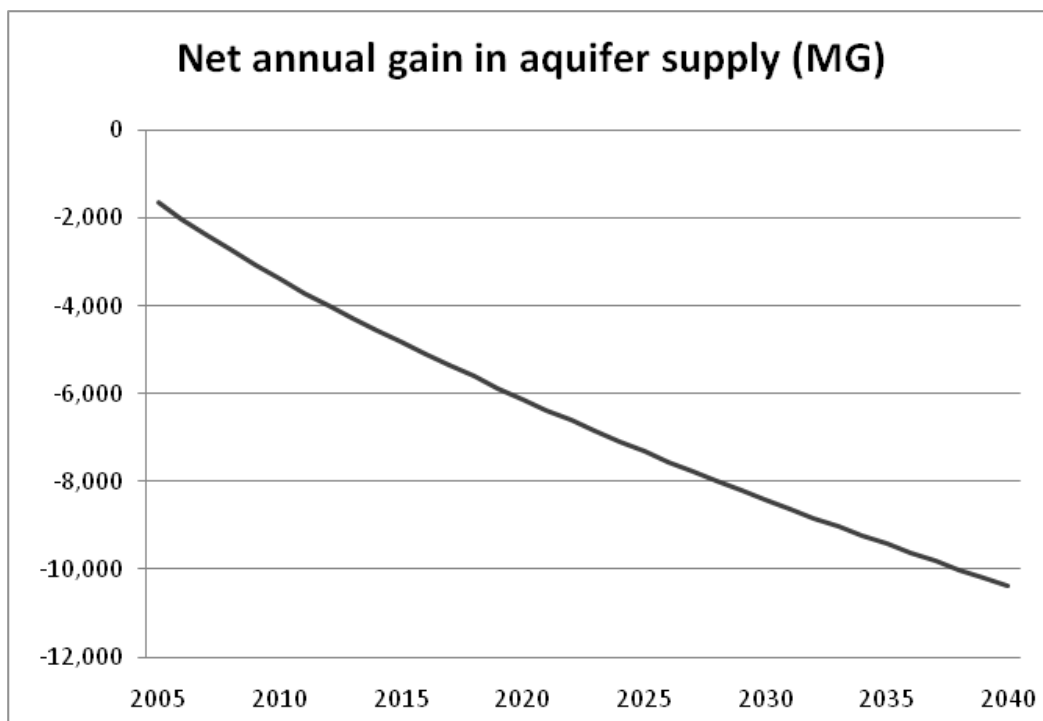


Figure 57. Scenario 2 results (Joint Base Lewis-McChord, WA).

### Scenario 3 – Status quo

Scenario 3 assumes a continuation of the status quo to include population growth trends, consumption rates, and precipitation patterns. It assumes a

decrease of 5 percent in aquifer recharge, but assumes the baseline values for changes in withdrawals by JBLM and by other groundwater users in the region (Figure 58).

#### **Scenario 4 — Water efficiency**

Scenario 4 assumes a regional level water conservation and efficiency program that significantly reduces water consumption at both the installation and the regional levels. Strategic intervention initiatives used in this scenario are a Public System Loss Management Program initiated in 2010, a Commercial/Industrial Water Conservation Program initiated in 2012, a Residential Water Conservation Program initiated in 2015, and an Agricultural Water Conservation Program initiated in 2018. Water reuse was not considered as an option for this analysis as it would require the development of a separate distribution system (Figure 59).

The Public System Water Loss Management Program consists of a 50 percent reduction in losses over a 2-year phase through a leak detection and remediation program. Current water losses are assumed to be roughly 10 percent at the regional level, based on national averages for public systems. At the installation level, current water losses are estimated to be closer to 18 percent based on information from the Fort Lewis Water Plan. Thus water losses in 2040 are expected to be closer to 5 and 9 percent at the regional and installation levels, respectively.

The Industrial Program consists of about a 39 percent reduction in industrial use over 8 years through a water conservation program. Traditional heavy industries could save nearly three-quarters of their total current water use by replacing large volumes of cooling and process water with recycled and reclaimed water. Other industries that could save large percentages of water use include paper and pulp, commercial laundries, and schools.

The Residential Program is meant to achieve a 39 percent reduction in use in older homes over the years 2015-23 with 90 percent market penetration. Even without improvements in technology, an almost 40 percent reduction in water use is estimated to be possible by replacing inefficient appliances and reducing leakage. In addition, a policy change requiring new homes to include ultra low flow toilets and showerheads will be implemented in 2015 that will have 100 percent penetration because it is required in the building code.

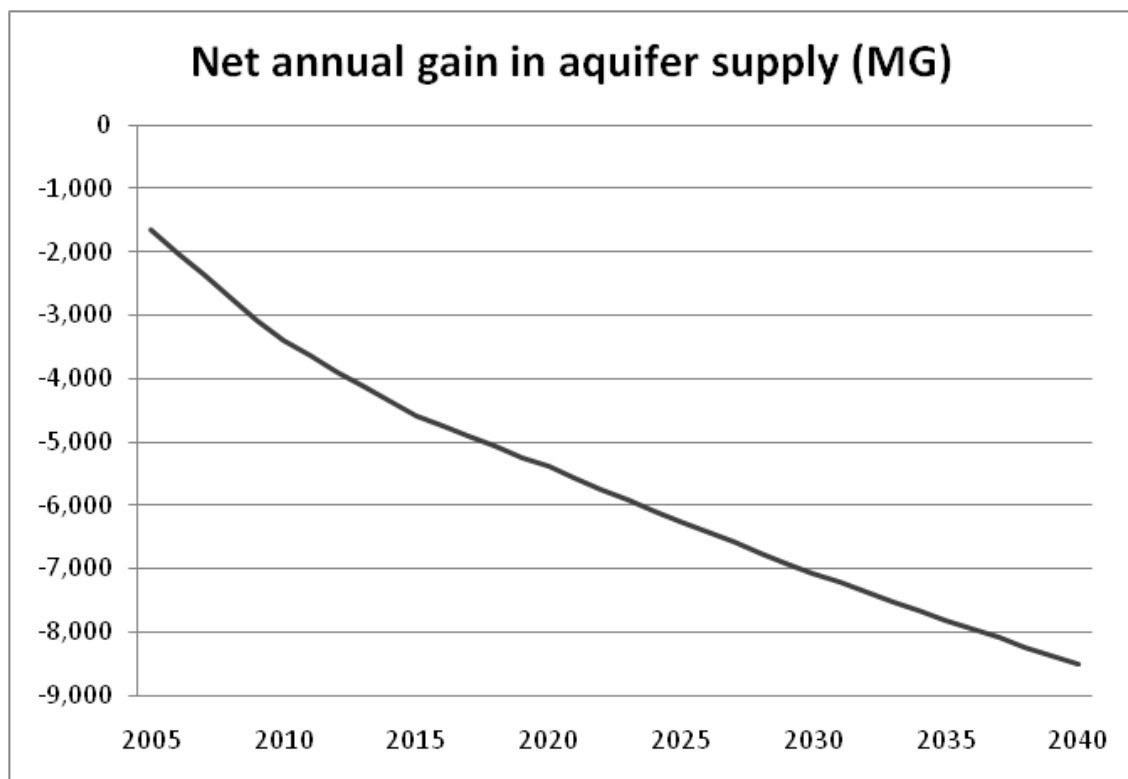


Figure 58. Scenario 3 results (Joint Base Lewis-McChord, WA).

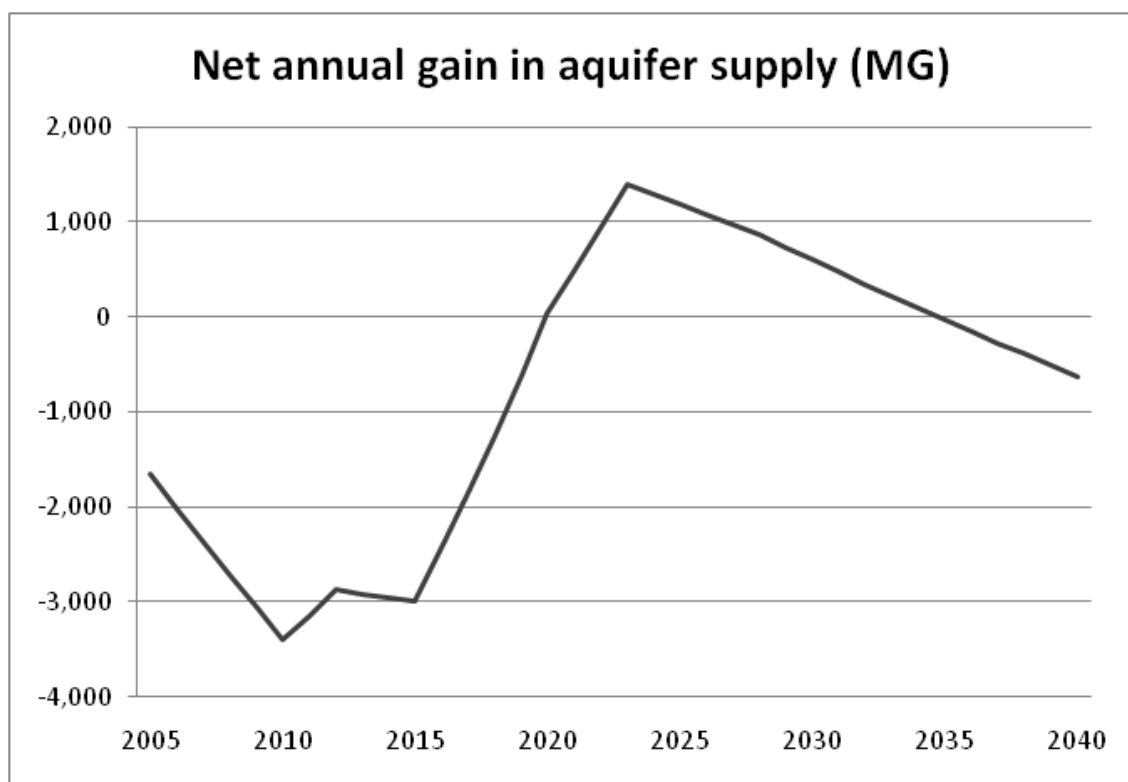


Figure 59. Scenario 4 results (Joint Base Lewis-McChord, WA).

The Agricultural Program consists of a 50 percent reduction in use over 10 years starting in 2018 based on irrigation efficiency improvement and reduction of usage. Much of the water consumed by the agricultural sector is used for irrigating food, fodder, and fiber crops.

### **Scenario 5 — Stormwater management Best Management Practices**

Most climate change models project that precipitation will increase in the Pacific Northwest in the coming years, but the existing stormwater management infrastructure will not be able to handle the change. Due to the amount of impervious surfaces in the study region, this increase in precipitation will not lead to an increase in aquifer recharge. It will likely cause storm sewers to flood, especially during extreme events, which may lead to cross contamination with sewage, further reducing the potable water supply. Scenario 5 assumes that all stakeholders in the study region, JBLM, surrounding municipalities, and residents, immediately begin employing stormwater management best management practices. These practices include bioswales, stormwater planters, green roofs, rain gardens, and increased detention/retention capacity. Scenario 5 assumes that when these methods are put into use, the amount of impervious surfaces in the study region will decrease, increasing the amount of area available for aquifer recharge. For the sake of this scenario, it is assumed that the stormwater management program adopted achieves a 10 percent increase in aquifer recharge from 2005 levels by 2040 (Figure 60).

### **Model results of the Joint Base Lewis-McChord regional supply model**

Since the absolute amount of water available in the Puget Sound regional aquifer system is unknown (the aquifers in the JBLM region that also give rise to Sequelitchew Springs) the regional supply model examined the net annual change in aquifer supply in millions of gallons. This was calculated by subtracting estimated withdrawals from estimated recharge.

The aquifer experiences a net annual decline in available water under every single scenario, including the baseline. However, there are notable differences in the quantity of the deficit across different scenarios. It is clear that, without intervention to decrease water demand or increase aquifer recharge, the aquifer begins to accrue significant water deficits of 20-30 MGD (Table 28).

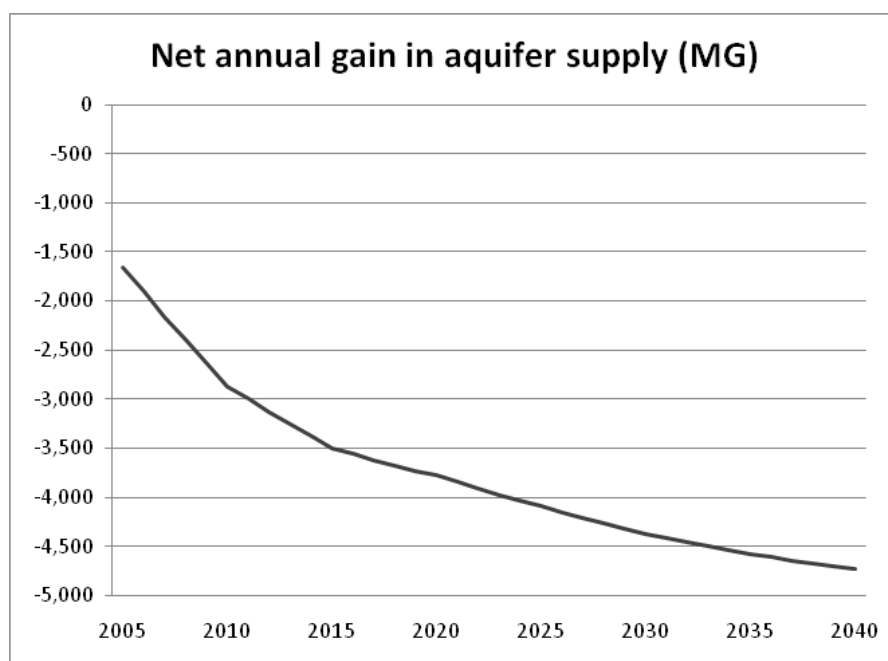


Figure 60. Scenario 5 results (Joint Base Lewis-McChord, WA).

Table 28. JBLM region scenario summary (MGD).

	Baseline 2005	Scenario 1: Climate Change 2040	Scenario 2: Increased Demand 2040	Scenario 3: Status Quo 2040	Scenario 4: Water Efficiency 2040	Scenario 5: Stormwater BMPs 2040
Aquifer recharge	68.98	62.08	65.53	65.53	65.53	75.88
Groundwater with- drawals by JBLM	4.14	3.85	3.94	3.85	3.64	3.85
Groundwater with- drawals by rest of region	69.37	84.99	90.01	84.99	63.60	84.99
Yearly gain in aquifer supply	-4.53	-26.76	-28.42	-23.31	-1.71	-12.97

Even with intervention, neither demand management nor stormwater BMPs alone can safeguard the local aquifer from drawdown and potential depletion. Rather, the two should be used in tandem to ensure a sustainable water supply over the long-term. If not, both JBLM and other regional groundwater users may be forced to look elsewhere to fulfill long-term water needs.

## Water sustainability assessment for the Joint Base Lewis-McChord region

At current aquifer recharge and water demand rates, the JBLM region is already using water from the local aquifer faster than it can recharge. This trend may be accelerated by population and industry growth. The Seattle-

Tacoma region has historically grown rapidly and will probably continue to do so; almost 5 million residents are expected to live in the MSA by 2030. New residents traditionally mean increases in water demand and increases in impervious surfaces, but that does not have to be the case.

The projected deficit is despite rainfall patterns, not because of them. The JBLM region receives a large amount of precipitation each year, significantly more than flows into the aquifer as recharge. The region is expected to receive more rain in coming years due to climate change. However, this water is not reaching the aquifer because of impervious surfaces that dominate the area. Unless an ambitious stormwater management plan is implemented, recharge will continue to drop and storm events will flood the combined sewers, potentially further reducing usable water supply due to contamination.

Stormwater management alone will not solve the region's water supply worries. Working to reduce demand now is critical to create a sustainable future water supply. Off-the-shelf water efficiency and conservation technologies have the potential to significantly reduce the region's water demand to below 2005 levels even for the next 30 years during which regional population growth will continue. Together, stormwater and demand management can create a sustainable groundwater future for the JBLM region.

## 9 McAlester Army Ammunition Plant, Oklahoma

McAlester Army Ammunition Plant (AAP) is located in southeastern Oklahoma. The plant is in Pittsburg County south of the Canadian River and Eufaula Lake, both of which border the county (Figure 61). The installation produces, stores, maintains, distributes, and demilitarizes munitions.

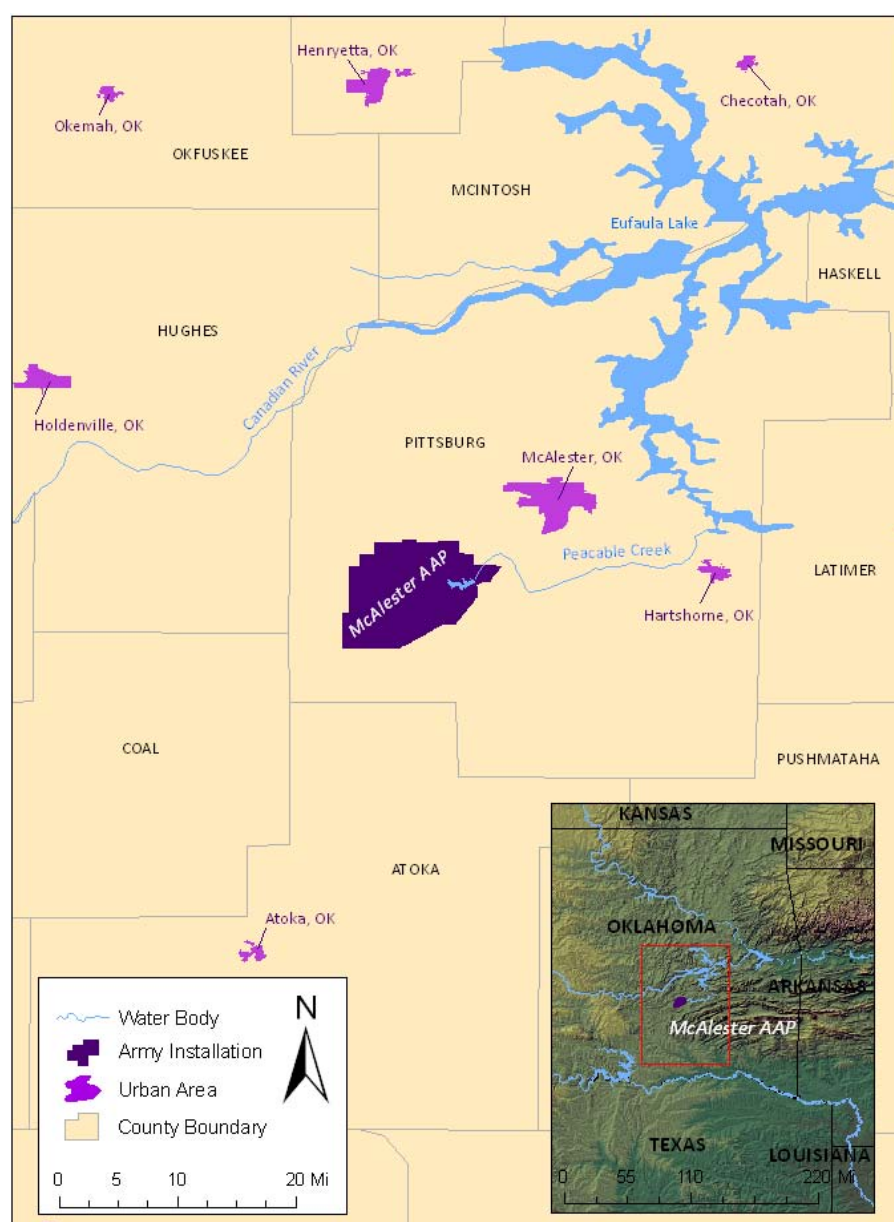


Figure 61. Location of McAlester Army Ammunition Plant.

An analysis was performed of the existing data on water availability and use for McAlester AAP and the nearby towns of Savanna and Haywood, which share McAlester's water source. Water use was then projected to 2040. Scenarios were then developed of water availability.

## **Regional characterization of McAlester Army Ammunition Plant**

Both natural and human systems define the McAlester AAP (MCAAP) region and shape the proposed water scenarios. McAlester depends entirely on Brown Lake for its water supply, thus only those areas that affect water supply for and demand from Brown Lake are included in the region.

### **Regional definition**

Brown Lake is at the headwaters of Peacable Creek, which empties into Eufala Lake and, eventually, the Canadian River. As such, the first withdrawals from the lake are made by McAlester itself and the two neighboring Pittsburg County communities of Savanna and Haywood. There are no upstream communities of the base that withdraw water that could limit water availability for the base. All of Brown Lake and the small streams that feed it are in Pittsburg County; therefore, the study region is confined to Pittsburgh County

### **Demographic trends\***

McAlester AAP supports a workforce of about 1500 personnel, with an additional part-time population of about 200 reservists for a month every summer. An additional 250 trainees will be added to the base population roughly two days each month once the new Air Force Reserve Command (AFRC) building becomes operational (Gatsche 2010).

Population projections prepared by the Oklahoma Department of Commerce were used to model future regional growth. Pittsburg County's population is estimated to be 45,211. This figure is expected to be 51,000 by 2040 due to expected growth. Savanna is expected to grow from 748 to 852 (14 percent growth). Haywood is not an incorporated town so it does not have an individual population projection. As a whole, the unincorporated areas of the county, including Haywood, are expected to grow by 13 percent. The projections use a net migration cohort component model to project population in 5-year increments out to 2030. Yearly populations

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\* The US Census Bureau's 2008 national population projections were used for future national growth. Historical population data was obtained from the US Bureau of Economic Analysis.



for years between the 5-year increments were extrapolated by assuming linear growth between each five year projection. Population for years beyond 2030 was estimated by using ordinary least squares regression to extend the trend observed between 2020 and 2030 for an additional 10 years (Wallace and Bettis 2002).

County growth is just at or below 200 people each year for an annual growth rate of about 0.4 percent (Wallace and Bettis 2002). The 0.4 percent rate is lower than that expected both for the United States and for Oklahoma alone over the same period. Such a disparity is generally consistent with historical trends over both the short, 1990-2007 and medium, 1969-2007, terms. Expected migration was made especially difficult to project as migration has been highly unstable throughout the state's recent history. Additionally, the use of net, rather than gross, migration to project this component of growth may introduce a slight distortion into the projections (Isserman 1993).

### **Water sources**

Brown Lake is the only water source for McAlester AAP. Brown Lake, and all the streams that feed it, lie entirely on installation property. Water is treated on-base and distributed to installation users, Savanna to the east, and Haywood to the north. The lake's current capacity is estimated to be 3616 AF. However, when first created in 1943, the lake held approximately 4525 AF (McAlester Army Ammunition Plant 2007). Although there was a recent proposal to dredge the lake and return it to its original capacity, such an action currently seems unlikely (Gatsche 2010). The spillway weir across the lake is 717 ft above mean sea level — water flows freely over this spillway into Peacable Creek so long as water levels are high enough. From Peacable Creek, water flows off-base, eventually flowing into Eufala Lake along the Canadian River. McAlester monitors a number of on-site solid waste management units to ensure that contamination from these units does not reach Brown Lake or other nearby surface or groundwater (McAlester Army Ammunition Plant 2001). Additionally, the installation can use Rocket Lake, upstream of Brown Lake or Brushy Creek Lake as alternate water supplies. Both are located on the installation, but in a different watershed (McAlester Army Ammunition Plant 2007). If the installation needed additional water, it would likely pursue water from the city of McAlester (Gatsche 2010).

## Climate

Pittsburg County is located in southeastern Oklahoma, encompassing the northernmost reaches of the Ouachita Mountains and the Hardwood Forests to their north. The area has a temperate climate and experiences all four seasons, though summer tends to last longer than winter. Temperatures average around 38 F in January and 82 F in July. Average yearly rainfall is about 45 in. The lowest precipitation generally occurs in winter with April and October being the wettest months of the year (Oklahoma Climatological Survey 2004; Arndt 2003).

Drought is a normal component of Oklahoma's climate (Wilkins 2006). Historical precipitation trends for the state show alternating periods of relative wetness and dryness lasting about 5–10 years, with the exception of a long period of relative wetness throughout the 1980s and 90s. These periods of dryness tend to correspond to periods of drought for the state (Oklahoma Water Resources Board 2007).<sup>\*</sup> More recently, the state experienced a drought during 2002–2006, with water availability dropping severely in 2006. During 2006, water levels in Brown Lake fell 4 ft below the top of the weir (1 ft below the bottom of the weir) (Hovell 2009).

Climate change is expected to greatly exacerbate water scarcity in the Great Plains. Current climate change models project marked increases in temperature, evaporation, and drought frequency. The most recent climate models project an average temperature increase of 5 to 7 F under a low emissions scenario and 8 to 10+ F under a higher emissions scenario. Precipitation is expected to stay relatively stable under a low emissions scenario and decrease under a higher one. While Pittsburg County's reliance on surface water, as opposed to groundwater, means that the area immediately around McAlester AAP will not also be challenged by diminishing stores of water in aquifers, these changes in precipitation and evaporation will still strain the area's water resources (US Global Change Research Program 2009).

## Soils and drainage

McAlester AAP and the Brown Lake watershed straddle two different physiographic provinces — the study area is one of ecological transition and the soils are diverse. The soil in the area is more impermeable than per-

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<sup>\*</sup> As the average precipitation for Pittsburg County is based on climate data from the 1970s onward, it is possible that 45 inches of rain is more rainfall than might be expected using longer-term numbers.

meable — roughly 75 percent of the watershed is made up of soils with low or very low infiltration rates. The 25 percent of soils remaining have moderate or high infiltration rates. The bedrock beneath these soils is impermeable, hampering water penetration far below the surface. Thus, groundwater is unlikely to reach Brown Lake.

#### **Land cover/use**

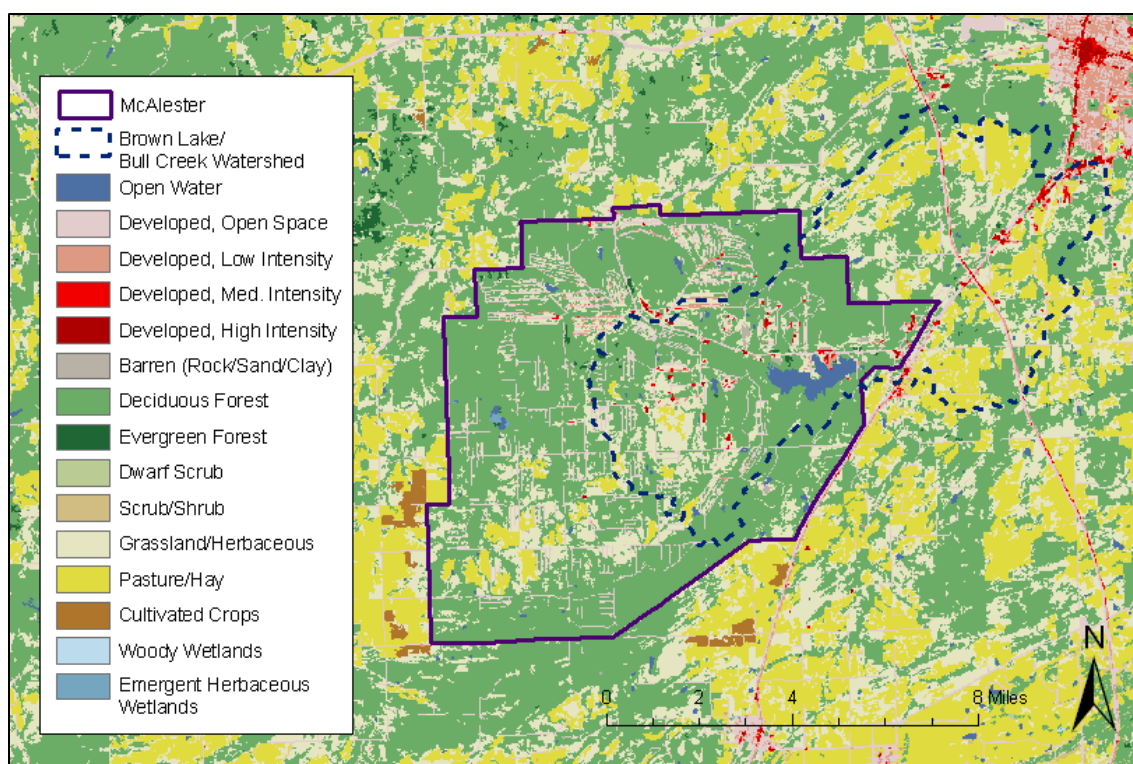
Brown Lake's watershed is dominated by undeveloped land, which, as of 2001, composed almost three quarters of the land cover in the region (Figure 62). Most of the remaining land is split between pasture and urban lands. Pasture is estimated to cover roughly 15 percent of the watershed, however most of the pasture land considered occurs off McAlester and downstream of Brown Lake. Urban lands cover about 10 percent of the watershed, though three fourths of those lands are considered "developed open space," roads, cleared areas alongside them, and other urban grasses (NLCD 2001). Roads are numerous on the installation connecting the many buildings.

The portion of the watershed that actually drains into Brown Lake is contained entirely within McAlester AAP's boundaries. This area is unlikely to change markedly in the coming years and thus land cover shifts are not expected to affect future water availability in Brown Lake.

#### **Historic water demand**

As of 2005, Pittsburg County used 11.76 MGD; 7 percent of that water, or 0.84 MGD, was used by McAlester AAP or one of the two towns the installation supplies. McAlester does not meter its water, with the exception of that used by Haywood and Savanna. Given that McAlester is an Army ammunitions plant, it is likely that the largest amount of water use on base is for industrial processes. Also, the installation must always have a large amount of water available at any given time to be prepared for the possibility of a fire — an obvious concern at an ammunitions plant; this water is treated to potable standards at the on-installation water treatment plant.

Water data are available for McAlester from 2003 through 2009. Water use rose and fell over that time period, beginning at 0.75 MGD in 2003, peaking at 0.84 MGD in 2005, and dropping to 0.62 MGD in 2009. The variability is likely due to the drought that occurred between 2002 and 2006 — droughts tend to increase the consumptive use of water.



Source: NLCD 2001

Figure 62. Land cover, McAlester Army Ammunition Plant.

For instance, Savanna's water use was particularly high during 2006, the worst year of the drought. Water was used for livestock — a use that is not necessary during years with regular precipitation. In addition to the drought, however, water use may have decreased after 2005 because of repairs to leaks in the water distribution system.

Water use for Pittsburg County as a whole has risen over the past 20 years from 5.58 MGD in 1985 to 11.76 MGD in 2005, though the magnitude of increases in use has decreased.\* The vast majority of the water used in Pittsburg County is surface water although some small amounts of groundwater are used for mining and livestock. The data listed in Table 29 provide details on water usage in Pittsburg County over the past 20 years.

### Developing the McAlester Army Ammunition Plant regional model

McAlester AAP obtains all its water from Brown Lake. The study region consists of the installation itself and the neighboring towns of Savanna and Haywood, which purchase water from McAlester.

\* The USGS collects data on county-level water usage every 5 years.

Table 29. Pittsburg County, OK historical water demand (MGD)

		Pittsburg County
1985	Surface	5.56
	Overall	5.58
1990	Surface	6.99
	Overall	7.89
1995	Surface	9.53
	Overall	10.49
2000	Surface	11.01
	Overall	11.43
2005	Surface	11.39
	Overall	11.76
Source: USGS 2005.		

### Water supply model

The model focuses on the long-term supply —out to 2040— provided by Brown Lake. Data from 2007 to 2010 are used as a baseline to match the demand projection baseline while trying to recreate a reasonably “typical” water year. Water availability to the installation is limited by (1) the physical capacity of Brown Lake, (2) the lake’s recharge rate, and (3) the legal and physical limits of the water treatment process.

### Drivers for water supply

#### *Brown Lake’s physical capacity*

When the Brown Lake dam was constructed in 1943, the lake had an estimated capacity of 4525 acre-feet (AF). However, sedimentation has reduced the lake’s capacity to approximately 3925 AF (McAlester Army Ammunition Plant 2007). If we assume that sedimentation rates are the same every year, which they are not in reality, the lake capacity decreases almost 9.4 AF per year. If we project this sedimentation rate out to 2040, the lake’s capacity would shrink to 3616 AF. This would change if the lake was dredged, a possibility that has been debated in the past. However dredging the lake comes with risks to the water supply — the lake is a Solid Waste Management Unit site managed for explosives. Although action is only necessary if lake sediments are disturbed, this occurs with dredging. It is unknown if there are any explosives present in the sediment.

### *The Brown Lake recharge rate*

Currently, Brown Lake is estimated to have an average yield of 6.5 MGD (McAlester Army Ammunition Plant 2007). This figure is a net estimate of runoff into the lake — the water from precipitation that reaches the lake not including any water that is lost to evaporation. Lakes in the eastern-most part of the state have an average evaporation rate of 48 in/yr (Oklahoma Water Resources Board 2007). Of course, the runoff rate could change over time because of changes in landcover within the watershed or due to climate change. Although limited future construction and demolition is planned on the installation these changes are expected to have negligible effect on recharge rates to Brown Lake. Climate change is projected to affect runoff more significantly. An analysis of 24 different climate models concludes that runoff will decrease from between 5 and 10 percent between 2041 and 2060 as compared to 1900-1970 levels (Lettenmeir et al. 2008). Coupled with the predicted decrease in recharge rates, temperatures will increase 1.5 to 6 F by 2050, an increase that will likely increase evaporation rates (US Global Change Research Program 2009).

### *Water treatment process limits*

Withdrawals from Brown Lake are limited by the processing capacity of water supply and wastewater treatment plants and the limitations specified in McAlester AAP's water withdrawal permit. The water supply plant currently has the capacity to treat 1.1 MGD although McAlester only has the right to pump ~0.8 MGD — though this permitted limit was exceeded in 2005 according to data from the installation's water plant (Oklahoma Water Resources Board 2000, McAlester Army Ammunition Plant 2009).

### **Water demand model**

The water demand model for the installation and co-users is based on initial demand data from 2003 to 2009 and incorporates population projections for the installation, Savanna, and Hayward. Water use in Savanna and Hayward is expected to grow at the same rate as the population. Installation water use is predicted using information about both population and real property change, that is, increase in square footage of facilities. Water use is predicted for different groups of buildings, for example, industrial, administrative, and housing. McAlester does not have water meters in its buildings. Accurately determining actual building-level water use could not be used to project future consumption rates. Instead, these projections are based on reports, anecdotal information from MCAAP per-

sonnel, and widely accepted building level water use factors (Billings and Jones 2008).

#### *Demand Model Results*

Table 30 lists the results of the demand projection for McAlester AAP. Without implementing any water efficiency measures, the combined water use for the installation, Savanna, and Haywood is expected to be 0.69 MGD by 2040 — a drop of just over 2 percent from baseline use. This drop is anticipated despite new buildings being completed or occupied and the additional training load expected due to the planned decrease in full-time civilian workers. If McAlester reduces water use by 2 percent per year out to 2020 to meet the requirements of E.O. 13514, 2040 demand is expected to be even lower at 0.57 MGD. Projected increases in demand are related to expected population and real property changes. As few changes are planned in either of these areas after 2012, the projected water demand is stable after that year.

#### *Meeting Water Usage Reduction Requirements*

Industrial/maintenance buildings and administrative and other moderate-user buildings are the two largest users of water (Table 31). Implementing water conservation and efficiency measures that affect these two categories of buildings will significantly reduce installation water use.

Obviously, any innovations that yield reductions in process-water use in ammunition production would yield savings, not only in potable water use, but also potentially at the other end of the pipe when it is time to treat pinkwater.\* Water use reduction possibilities may also exist in situations where water is being used as a coolant for machinery through ensuring that systems re-circulate coolant water and that water released to discard solids is minimized.

Table 30. MCAAP projected water demand (2010-2040), MGD.

	2010	2015	2020	2025	2030	2035	2040
McAlester demand	0.624	0.565	0.565	0.565	0.566	0.566	0.566
Savanna/Haywood demand	0.110	0.113	0.116	0.118	0.121	0.123	0.125
Total demand	0.735	0.678	0.681	0.683	0.686	0.688	0.691
Total Demand with 2% reductions	0.722	0.611	0.558	0.560	0.563	0.566	0.568

\* Pink water is a byproduct of equipment washing processes that occur with munitions filling or demilitarization operations; pinkwater is considered a hazardous waste.

Table 31. McAlester Army Ammunition Plant baseline water use by building type.

Usage (KGD )	Baseline
Family Housing	5.15
Reservists	1.67
Medical	1.24
Industrial/Maintenance	212.10
Lodging	5.10
Administration/Moderate Users	193.84
Community and Commercial: Non-food related	33.34
Community and Commercial: Food-related	4.53
Storage	18.92
High Water Use Facilities	17.10
Irrigated/Improved Land	4.93
Losses	97.28
Annual Average Usage	705.31

Water use in administrative buildings is generally for toilet flushing, sinks, and in some cases, showers. Retrofitting or replacing older fixtures with newer, more water-efficient fixtures would result in significant water savings in these buildings. WaterSense labeled fixtures are 20 percent more efficient than the average industry products, meaning that replacing or retrofitting a building to WaterSense labeled fixtures should yield a drop in that building's water use by one fifth (USEPA 2010).

Reducing water use in the on-site laundry would save thousands of gallons per day because it is likely that the laundry is the greatest single water user on the installation (Gatsche 2010). Ensuring that the technology in this facility is current and operated as designed is an important part of minimizing water use.

Finally, steps to minimize water loss are expected in the near future with the planned water main replacements scheduled for December 2010. Water loss on Army installations through distribution system leaks is sometimes higher than in municipal systems because maintenance funds to detect and fix leaks have not been readily available. McAlester AAP's water distribution system in particular is likely to have a large number of leaks because of the many long distribution lines, both to supply water to Savanna and Haywood, and to ensure an adequate level of fire protection, which is central to the mission of an ammunition plant.

In addition to leaks, the necessity of treating significant amounts of water in excess of what is otherwise needed in case of a fire also means that, at times, more water is treated than can be used before water quality issues arise. This results in additional loss as water is released back into the environment. Any water released in this manner is not necessarily lost to the



system — much of it flows back into Brown Lake where it is available to be treated again. Nonetheless such water is still considered “used potable water” with regard to E.O. 13514 so minimizing such released water may also help McAlester meet the executive order requirements.\*

## **McAlester Army Ammunition Plant 2040 water availability scenarios**

The objective of this study was to evaluate water sustainability 30 years into the future. The baseline water supply and demand were projected to the year 2040.

### **Scenario 1 — Status quo**

Scenario 1 represents a water supply outcome in which current trends continue into the future bringing only gradual change to current water availability. The water demand projection described above, which is based on current expected population and real property changes, is assumed to hold true. Climate change is assumed to affect the water situation only minimally with a 4 percent decrease in runoff into, and a 5 percent increase in evaporation from Brown Lake by 2040. Furthermore, sedimentation is expected to continue at the rate observed above. Finally, as an approximation of the requirement of E.O. 13514, McAlester AAP is expected to reduce water use by 2 percent per year through 2020.

### **Scenario 2 — Extreme climate change**

Scenario 2 explores a water future in which climate change occurs along the most extreme end of the range of potential effects currently projected for the region. Instead of a 4 percent decrease in runoff by 2040, runoff is assumed to decrease by 8 percent. Instead of a 1 percent increase in evaporation, evaporation is expected to increase by 10 percent. Additionally, water demand from Savanna and Haywood is assumed to increase slightly faster than is currently anticipated as ranchers start to rely more on these water supplies in the wake of dryer regional conditions. As a result, water demand from the area is expected to be 0.01 MGD higher in 2040 in this scenario than in the status quo scenario. This increase is equivalent to half the difference between Savanna’s demand in 2006, during the drought when ranchers were unable to use rainwater to fill tanks for their cattle, and Savanna’s baseline demand. Other factors — sedimentation and annual water use reductions — remain the same from the previous scenario.

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\* While using non-potable water to supply fire-fighting readiness needs is technically feasible, the costs, adding basic water filtering, creating a dual pipe system, could be cost prohibitive.

### **Scenario 3 — Increased demand**

This scenario explores the possibility of more demand than is expected, both from the installation and Savanna/Haywood. In this scenario, it is assumed that installation demand increases without the mitigating affect of the 2 percent annual reductions. Due to anticipated decreases in the number of full-time civilian workers on-base, water demand for the installation is still expected to decrease slightly over that time, but not nearly as much as is anticipated in the status quo scenario. Additionally, this scenario supposes that a new industry moves into Savanna starting in 2016, increasing anticipated demand for that town by 75 percent over a 5-year period. Other factors — sedimentation, runoff and evaporation — remain the same as for the status quo scenario.

### **Scenario 4 — Worst case supply + max pumping demand**

This scenario presents a worst-case scenario — combining the decrease in supply stipulated in the extreme climate change scenario and the gradual increase to full capacity pumping (1.1 MGD) from the water treatment plant. Such greatly increased demand is unlikely. However, examining the implications of full capacity treatment for water availability is still useful. The final factor — the sedimentation rate — is the same as the status quo scenario.

### **Scenario results**

On average, runoff into Brown Lake is currently estimated at 6.5 MGD. In the mild climate change scenarios this is reduced to 6.24 MGD. In the extreme climate change scenarios, to 5.98 MGD. With a maximum physical treatment capacity of 1.1 MGD and a maximum legal withdrawal permit of 0.8 MGD, on average, McAlester AAP is not in danger of experiencing water scarcity anytime soon.

Of course, rain does not fall “on average,” so in addition to examining average anticipated recharge, the analysis incorporated estimates of the time needed for water levels in Brown Lake to decrease in various scenarios (Table 32).

Table 32. Scenario results.

Scenario	Days without rain needed for lake to drop...		
	1 ft	4 ft	Completely
Baseline (2009)	67	269	477
Status Quo (2040)	68	273	446
Extreme Climate Change (2040)	65	262	428
Increased Demand (2040)	63	253	413
Worst Case Scenario (2040)	55	220	360

These estimates suggest that, regardless of which scenario best represents future water conditions in and around McAlester, the water situation will not change drastically over the coming decades. With the exception of the worst-case scenario, it should take more than a year without rain to completely deplete Brown Lake at anticipated consumption levels. Even in the worst-case scenario, depletion would take a full year.

Nonetheless, water availability is expected to gradually decrease over the coming years. Even in the status quo scenario, in which it takes slightly longer for water levels to drop than in the baseline scenario, the water situation appears more positive than in the baseline scenario because water demand is expected to decrease. In the extreme climate change scenario, even decreased demand cannot offset the decreased availability to maintain the same water availability as in the baseline scenario. Of course, the above findings do not completely eliminate the possibility of short-term water scarcity during longer periods of recurrent severe-extreme drought conditions that occurred in the region during the mid-1950s.

### **Water sustainability assessment for the McAlester Army Ammunition Plant region**

Overall, it is clear that water scarcity is not an especially large risk for McAlester AAP. Nonetheless, because drought is expected to occur with increasing regularity in this region in the coming years, it is important for the installation to be ready for the possibility of a severe drought, and have plans in place for early response to potential drought conditions. Additionally, McAlester should work with Savanna and Haywood to ensure that they have adequate drought plans in place. Recognizing and responding to droughts early is essential to successfully maintaining water supply until the drought is over.

## 10 Fort Riley, Kansas

Fort Riley was established in 1853 to protect people and trade along the Oregon-California and Santa Fe trails. Since its founding, Fort Riley has been an important site for various military uses because of its large size, currently over 100,000 acres, and central location. After the Civil War, Fort Riley became a major US Cavalry post, a school for cavalry tactics and practice, and a base from which missions against Native Americans were conducted. In 1887, Fort Riley became the site of the US Cavalry School. During World War I, the post saw great expansion and was home to over 50,000 soldiers. During World War II, approximately 125,000 soldiers trained at Fort Riley (Fort Riley 2009).

Today Fort Riley is the headquarters of the 1<sup>st</sup> Infantry Division, known as the “Big Red One.” In 2003, approximately 11,400 Soldiers and civilian workers were based at Fort Riley. By 2013, Fort Riley’s population will be approximately 21,000 (Balocki 2008). By 2015, the military and civilian population is expected to exceed 26,000, a 72 percent increase from 2005 (Fort Riley Comprehensive Energy and Water Master Plan 2010).

Fort Riley is located within the Manhattan, Kansas Metropolitan Statistical Area (MSA), which includes Riley, Geary, and Pottawatomie counties. In 2008, the MSA was estimated to be home to 122,000 people, but official population projections estimate that the population will decline somewhat between now and 2025 (US Census Bureau and Kansas Division of the Budget 2009).

A regional water balance is used to analyze potential future water availability and policies that may aid in maintaining a sustainable water supply in the Fort Riley region and to support the military mission at the Fort.

### Regional characterization of Fort Riley

#### Demographic trends

Fort Riley is located in northwest Kansas, about 14 mi west of the city of Manhattan and 60 mi west of Topeka. Manhattan, known as “The Little Apple,” is home to Kansas State University, which along with Fort Riley is a major employer in the area (City of Manhattan 2009) (Figure 63).

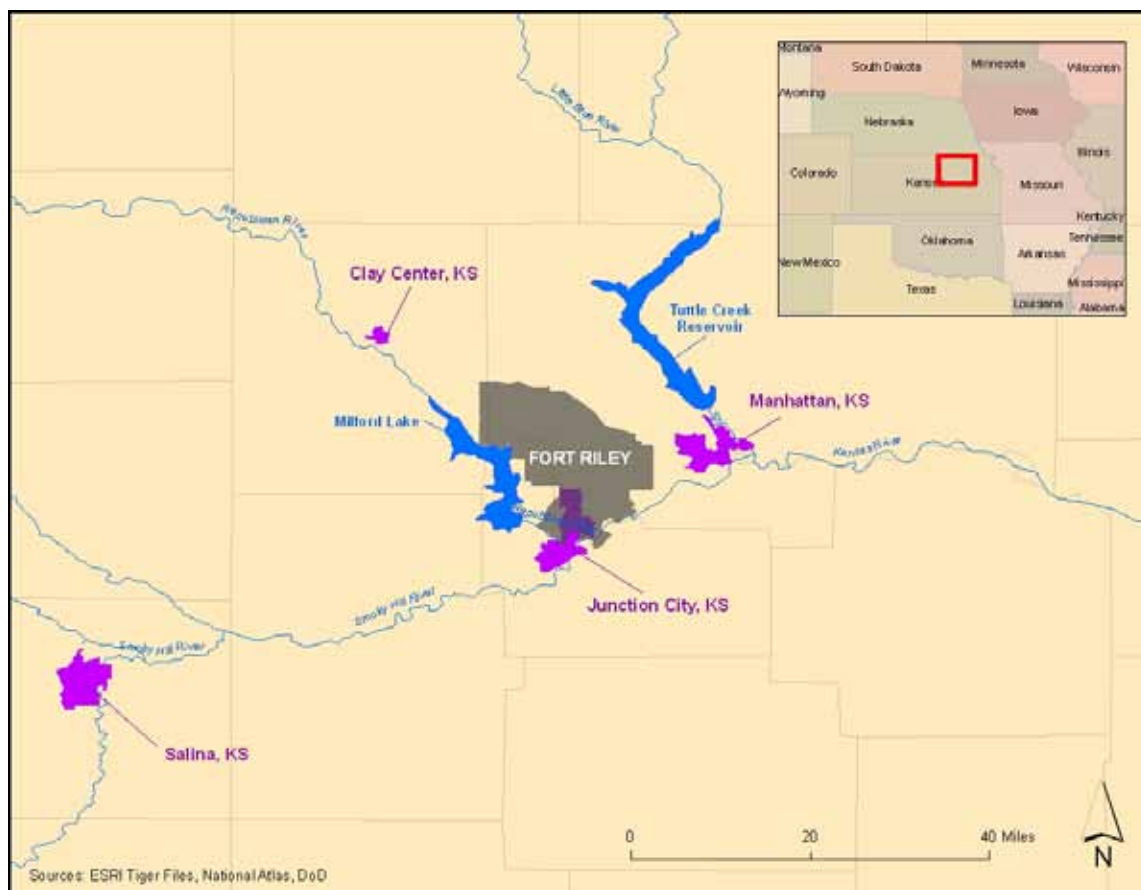


Figure 63. Location of Fort Riley, Kansas.

Fort Riley spans Riley and Geary counties. The first Federal decennial census to include these counties was in 1860, and listed 1224 residents in Riley and 1163 residents in Geary. In 2008, these counties had an estimated 71,069 and 31,171 residents, respectively. The three-county MSA saw its population increase steadily between 1940 and 1990. Riley County's population increased 226 percent during that 50-year period. The MSA's population peaked in 1990. By 2000, the population had dropped to 109,000 (US Census Bureau 2010). Figure 64 shows the long-term population trend in the MSA.

Official population projections estimate that by 2025, population will drop even further to 106,403 (Kansas Division of the Budget 2009) (Table 33). The state of Kansas has only issued population projections up to the year 2027. Outside of Fort Riley, the MSA's largest cities are Manhattan (Riley County), and Junction City (Geary County). Their estimated populations for 2008 were 52,284, and 20,671, respectively.



Figure 64. Historic population growth in the Manhattan, KS, Metropolitan Statistical Area.

Table 33. Population projections for the Manhattan, KS, metropolitan statistical area.

	Projected			
	2010	2015	2020	2025
Geary	26,053	25,983	25,826	25,600
Pottawatomie	19,320	19,153	18,913	18,727
Riley	63,210	62,992	62,608	62,076
Total	108,583	108,128	107,347	106,403

Sources: US Census Bureau 2010, Kansas Division of the Budget

### Regional definition

Since Fort Riley depends entirely on groundwater withdrawn from alluvial aquifers along a particular stretch of the Republican River, as explained in the following section, the study region is contained within the Lower Republican River watershed, which includes parts of nine counties. However, Dickinson and Mitchell counties have very little area in the watershed and are not considered relevant to the study region. The study region consists of portions of Riley, Geary, Clay, Washington, Cloud, Republic, and Jewell counties. Manhattan was not included in the study region of because it is downstream from Fort Riley and withdraws water from alluvial aquifers along the Kansas River, not the Republican (City of Manhattan 2009) (Figure 65).

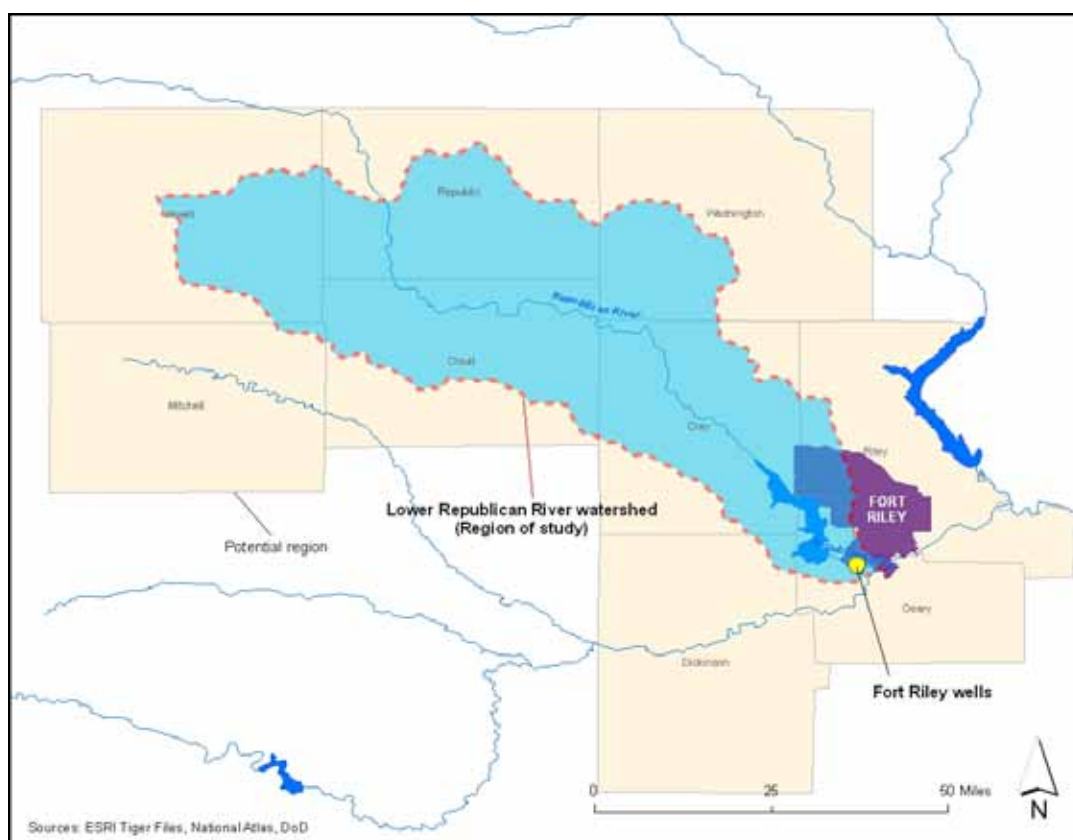


Figure 65. Fort Riley study region (blue area within dotted line).

### Water sources

The communities within the study region rely primarily on groundwater withdrawals from stream-valley (alluvial) aquifers along the Republican River before its confluence with the Smoky Hill River. The surficial aquifer system in Kansas, Missouri, and Nebraska is made up of unconsolidated sand and gravel and consists of three types of aquifers: stream valley aquifers, the Mississippi River Valley alluvial aquifer, and glacial-drift aquifers. In some places, these different types of aquifers are hydraulically connected. Most of the water in this surficial aquifer system is found in the water table.

The stream-valley aquifers in the region are made up of mostly sand and gravel, and vary in thickness from about 90 to 100 ft, but can be up to 160 ft deep. Stream-valley aquifers are typically recharged by precipitation falling directly on the aquifer, but recharge can also occur through: (1) seepage from streams and other water bodies in the stream valleys, (2) downward percolation of applied irrigation water, and (3) groundwater inflow from permeable bedrock underneath the aquifer. Networks of canals and irrigation ditches that divert water from some streams, notably the

Arkansas, the Smoky Hill, and the Solomon Rivers, reduce the amount of water available to recharge the stream-valley aquifers. Between these diversions and intense irrigation pumping, streamflow has greatly declined and some perennial streams are now dry most of the year.

These stream-valley aquifers are reliable sources of groundwater due to their coarse-grained nature and high permeability. Typical yields of wells in these aquifers vary from 100 to 1000 gpm. Some wells in Kansas have even been reported to produce up to 3000 gpm (Miller and Appel 1997).

The Republican River is formed by the confluence of the North Fork Republican River and the South Fork Republican River, both of which have headwaters in the High Plains in northeastern Colorado. The confluence of the Republican River and the Smoky Hill River forms the Kansas River near Fort Riley. The Republican River is about 550 mi long, about 100 mi of which are in Kansas. The Republican River is impounded by Milford Dam near Fort Riley, creating Milford Lake. The lake abuts Fort Riley at the western part of the installation.

Average daily streamflow in the Republican River at Junction City has been declining slightly since 1964 (Figure 66). Streamflows at points upstream on the Republican River, Clay Center and Concordia, have also been declining slightly, at about the same rates as at Junction City. Declining streamflow could indicate reduced amounts of water in these aquifers because water levels in the stream-valley aquifers are directly related to river levels. (US Geological Survey 2010c).

### **Water rights**

The Republican River Compact allocates all of the waters of the Republican River basin between Colorado, Nebraska, and Kansas. Colorado is permitted to use an annual total of 54,100 acre-feet, Kansas 190,300 acre-feet, and Nebraska 234,500 acre-feet (Republican River Compact 1942). In 1998, Kansas filed a complaint with the US Supreme Court claiming that Nebraska had violated the Compact by allowing the unimpeded construction of thousands of wells that were hydraulically connected to the Republican River and its tributaries. Kansas also accused Nebraska of using more water than it was allowed under the Compact, thus depriving Kansas of its full claims. The state of Colorado was also added in the lawsuit since the headwaters of the Republican River are located there, making the case *Kansas v. Nebraska and Colorado* (Colorado Division of Water Resources 2010).



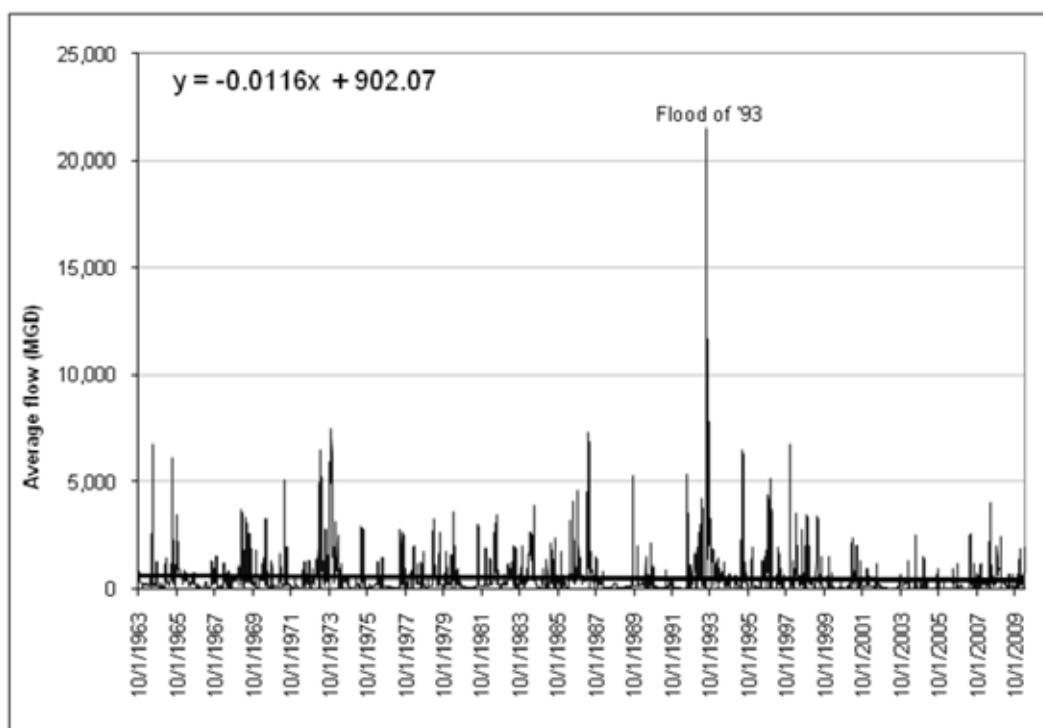


Figure 66. Average daily streamflow in the Republican River at Junction City, KS.

The case was settled in 2003, and during that year the three states reached agreement on the Republican River Compact Association (RRCA) groundwater model (Kansas Department of Agriculture 2010). However, continued disputes over Nebraska's alleged overuse of water, and the disagreement over Colorado's plan to build a pipeline to the North Fork Republican River from a wellfield several miles to the north of the river, highlight the complexity of water rights issues in the Republican River basin. As a military installation, Fort Riley is not subject to state water regulations. However, due to the interconnectedness of the surface and groundwater systems in the area, the amount of water that other users are allowed to withdraw from the rivers and its alluvial aquifers affect the supply available to Fort Riley.

### Climate

Fort Riley is located in northeast Kansas, which has a temperate climate with significant seasonal changes in temperature and precipitation. January is the coldest month, with an average temperature of 27.8°F, and July is the warmest month, with an average temperature of 79.9°F. The average annual temperature in Manhattan, Kansas, is 54.9°F. Between 1971 and 2000, average annual precipitation was 34.8 in., with most precipitation occurring between April and September (Coiner et al. 2010).

## **Topography**

Fort Riley is in the Osage Plains section of the Central Lowlands physiographic province. This area is characterized by streams and river valleys with associated alluvial floors and terraces, uplands consisting of resistant limestone layers, and scattered hill country that includes the Flint Hills. Fort Riley is situated between two large reservoirs, Milford Lake to the west and Tuttle Creek Lake to the northeast.

Milford Lake is the largest man-made lake in Kansas. An impoundment of the Republican River, the lake's 15,700 acres of water area are maintained by the US Army Corps of Engineers (USACE) for recreational, flood control, and water supply. Since its creation in 1967, the average daily water level in Milford Lake has remained constant overall at about 1145 ft mean sea level. Tuttle Creek Lake is an impoundment of the Big Blue River and is also managed by USACE. It was constructed in 1962 for the purpose of flood control, and also includes recreational areas (USACE Kansas City District 2010).

The Fort Riley area is underlain by sedimentary rocks made up of limestone, limestone with flint, and shale. Soil depth and characteristics vary depending on location. Soils are deep and fertile along streams, but in hilly areas they are thinner (Coiner et al. 2010).

## **Land use**

Land use in the study region is mostly grassland and cultivated crops. Developed land is concentrated in the Junction City, Fort Riley North, Clay Center, and other urban areas, and there are areas of deciduous forest along creeks and streams. Spots of pasture and hay also dot the study region (Multi-Resolution Land Characteristics Consortium) (Figure 67). Office buildings, barracks, and other buildings on Fort Riley are mostly located in the southern areas of the installation. Land in other parts of Fort Riley is used for military training purposes, including live-fire training (Coiner et al. 2010).

## **Historic water demand**

Between 1985 and 2005, total water withdrawals in the study region decreased by almost 30 percent. Groundwater withdrawals decreased almost 50 percent during that 20-year period, and surface water withdrawals decreased 35 percent.

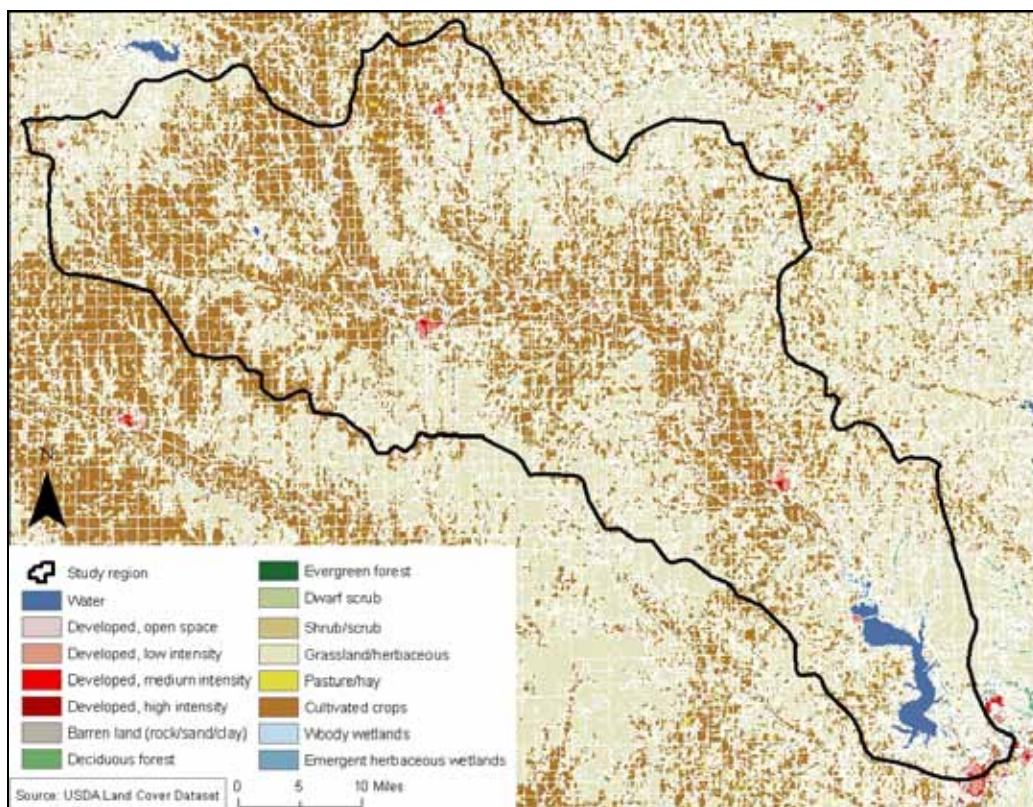


Figure 67. Land use in the region of study.

## Developing the Fort Riley regional model

Fort Riley currently obtains its drinking water from eight alluvial groundwater wells along the Republican River below Milford Lake before its confluence with the Smoky Hill River (Centers for Disease Control and Prevention 2009). Most of the other groundwater withdrawals in the study region are also from alluvial aquifers along the Republican River (Figure 68)

### Water supply model

The baseline year for this study is 2005 as this is the latest county-level water use data available from the USGS. Water supply is projected under several scenarios out to 2040.

### Drivers for Water Supply

The main driver for groundwater supply is the change in storage in the alluvial aquifers along the Republican River. The change in storage includes recharge (precipitation, seepage from the Republican River, and subsurface flow), loss due to evapotranspiration, Fort Riley withdrawals, and the region's other groundwater withdrawals.

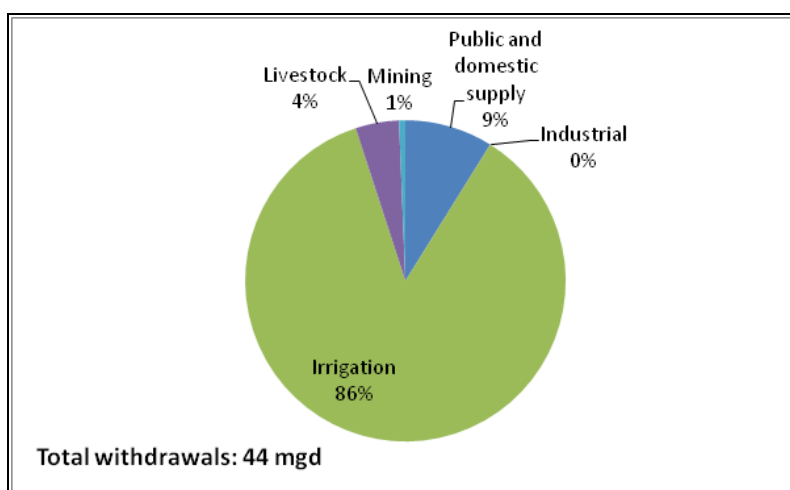


Figure 68. Regional water withdrawals from Republican River aquifers in 2005, by use.

Past research on aquifers in the area determined that the recharge rate from precipitation for the alluvial aquifers in the Fort Riley area is about 1.94 MGD, seepage from the Republican River is about 8.05 MGD, and flow from underlying aquifers is about 0.43 MGD (Myers et al. 1996).

### Water demand model

The Fort Riley study region's water demand projection is based on the initial 2005 consumption baseline and the population projections for the study region. These projections were calculated by multiplying the estimated 2005 population and population projections for each county by the percentage of the county in the watershed. The region's estimated future withdrawals were calculated using the total estimated withdrawals divided by the population for 2005. The resulting ratio was for total population compared to withdrawals in gallons per capita per day (gpcd). These ratios were multiplied by the estimated population for each year up to 2040, assuming a 1 percent annual decrease in the gpcd value because of increased water efficiency. The model also assumes that the ratio of groundwater withdrawals to surface water withdrawals do not change from the 2005 baseline.

#### *Fort Riley Water Demand Model*

The Fort Riley Water Demand Projection uses historical water use data, real property data, planned construction, and population projections for the installation to predict future water use. Water use is predicted by building category, such as family housing, industrial, and storage. As the installation does not have individual building water meters, building level

water factors were used to predict the amount of water used per building — or in the case of barracks and family housing, per resident (Billings and Jones 2008). Local evapotranspiration is also taken into account to help predict water use for irrigation.

Assuming that Fort Riley's water use decreases 2 percent every year through 2020, as required by E.O. 13514, water demand is expected to follow an increasing trend and peak at 3.22 MGD in 2016, dropping to 2.92 MGD by 2020. Army population and construction estimates for Fort Riley only exist out to 2018. Water demand after 2020 is projected to remain constant at 2.92 MGD (Figure 69).

#### *Model Results*

Total withdrawals are expected to decline into the future as regional population declines (Figure 70).

### **Fort Riley 2040 water availability scenarios**

The objective of this section is to project water availability 30 years into the future based on several scenarios. The 2005 baseline is projected to the year 2040 for both the supply and demand models.

#### **Scenario 1 — Climate change**

Across the Central Great Plains, which includes Kansas, average temperatures have risen more than 2°F during the last century. Many areas of the Great Plains have seen increased precipitation over the last 100 years, mostly in the form of high intensity events. The two primary models used to predict changes in climate for the US National Assessment on Climate Change are the Hadley and the Canadian models. Both models project a greater number of days over 90°F in the Great Plains over the next century. Seasonally, more warming is projected during the winter and spring than during the summer or fall. The Hadley model projects an increase in precipitation in many parts of the Great Plains, but the Canadian model actually projects a decrease of 25 percent in some areas, including western Kansas. According to the US National Assessment on Climate Change, even if precipitation increases, increased evaporation due to rising temperatures will result in net soil moisture declines for most of the region (National Assessment Synthesis Team 2000). Scenario 1 assumes a net decrease in aquifer recharge and baseline values for Fort Riley and other regional groundwater withdrawals (Figure 71).

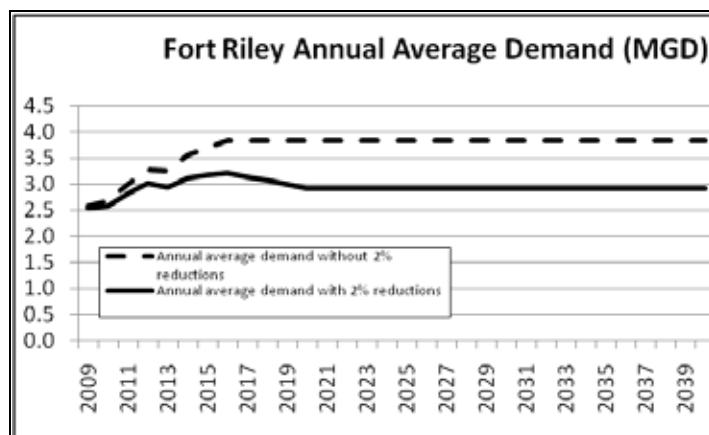


Figure 69. Fort Riley water demand projection with and without water efficiency reductions.

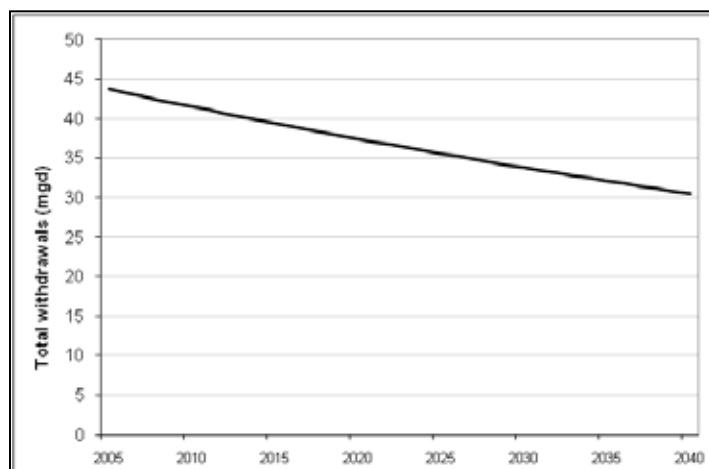


Figure 70. Baseline demand projection for the Fort Riley region.

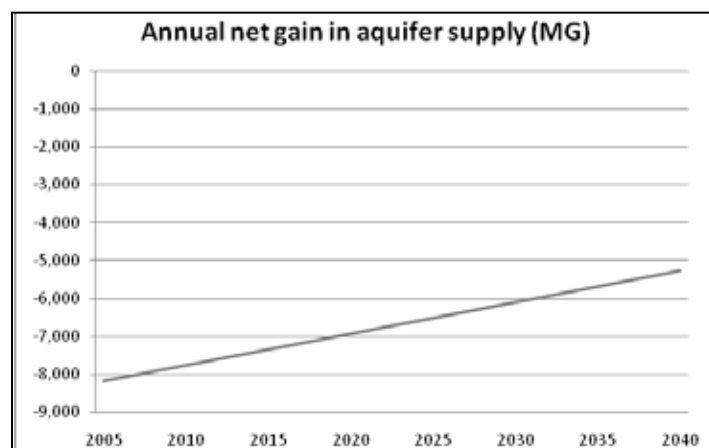


Figure 71. Scenario 1 results (Fort Riley, KS).

### Scenario 2 — Greater demand

Scenario 2 assumes population growth in excess of what is currently projected, both at Fort Riley and in the larger region. Regionally, this means

maintaining instead of losing population. On the installation this could be due to a mission change that results in more people and/or buildings using more water on the installation than expected. For the region, it is assumed that without population decline, water withdrawal levels will hold steady, whereas for the installation, the 2 percent yearly water use reductions are not met. Supply variables are assumed to continue following current patterns: precipitation patterns stay the same and only a slight decrease (2 percent) in aquifer recharge is assumed (Figure 72).

### Scenario 3 – Status quo

Scenario 3 assumes a continuation of the status quo that includes current population projections and consumption rates and current precipitation patterns. It assumes a 2 percent decrease in aquifer recharge, but assumes that the baseline values for withdrawals by Fort Riley and other groundwater users in the region are valid (Figure 73).

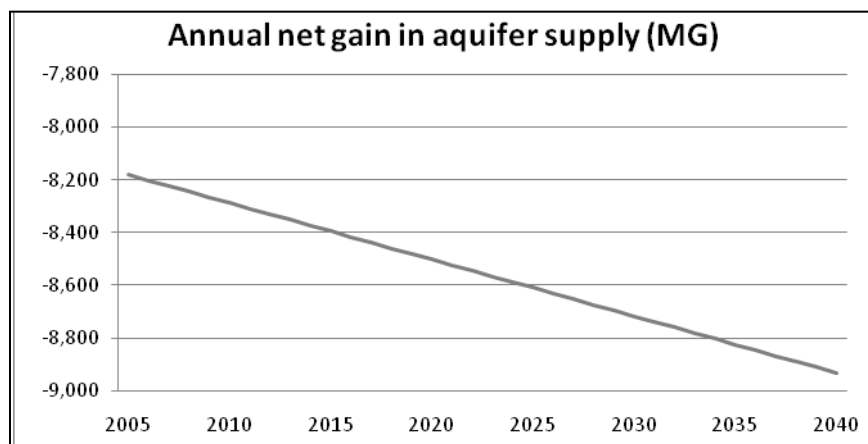


Figure 72. Scenario 2 results (Fort Riley, KS).

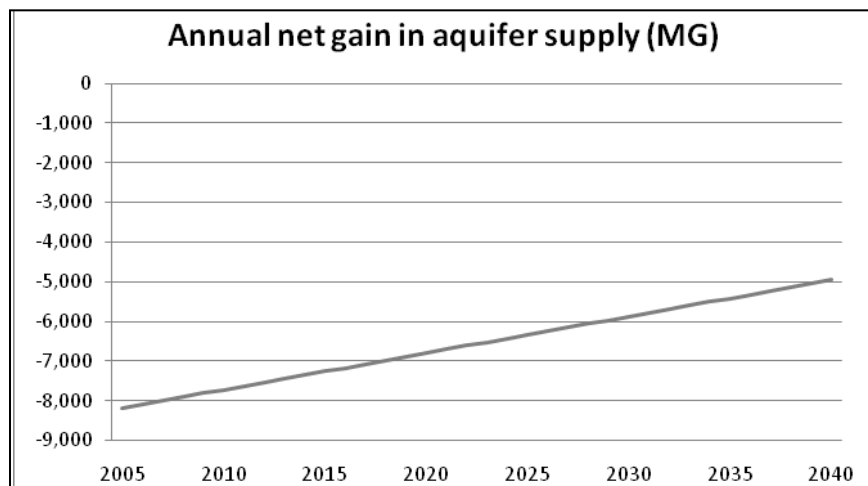


Figure 73. Scenario 3 results (Fort Riley, KS).

#### **Scenario 4 – Water efficiency**

Scenario 4 assumes a regional level water conservation and efficiency program that significantly reduces water consumption. Strategic intervention initiatives used in this scenario are a Public System Loss Management Program initiated in 2011, an Agricultural Water Conservation Program initiated in 2016, and a Residential Water Conservation Program initiated in 2019. Water reuse was not considered as an option because a separate distribution system would need to be designed and constructed. There are no plans to seek funding for such a system. The Public System Water Loss Management Program consists of a 50 percent reduction in losses over a 2-year time frame - through a leak detection and remediation program.

The Residential Program would result in a 39 percent reduction in water use in older homes starting in 2019 and continuing over 8 years with 90 percent market penetration. Even without technology improvements, a reduction of almost 40 percent in water use was estimated by replacing inefficient toilets, washing machines, showerheads, and dishwashers, and by reducing leaks. In addition, a policy change requiring new homes to include ultra low flow toilets and showerheads is implemented in 2016 with 100 percent penetration driven by compliance with the building code. The Agricultural Program consists of a 50 percent reduction in use over 10 years starting in 2019 based on irrigation efficiency improvements and use reduction (Figure 74).

#### **Scenario 5 – Upstream diversion (Fort Riley, Kansas)**

Scenario 5 assumes that upstream water users begin diverting more water from the Republican River and its tributaries. It is assumed that this affects the Fort Riley region's water availability by decreasing the amount of seepage that flows from the river into the alluvial aquifers. Ten percent more groundwater is withdrawn beyond the already expected decreases (Figure 75).

#### **Scenario results**

How much water is available in the alluvial aquifers along the Republican River is unknown. Thus, the regional supply model examined the net annual gain in aquifer supply in millions of gallons, calculated by subtracting estimated annual withdrawals from estimated annual recharge (Figure 76).



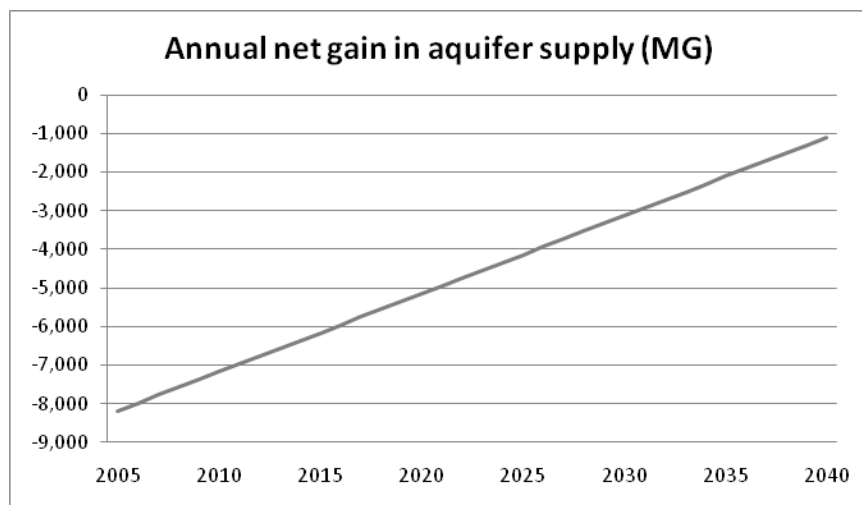


Figure 74. Scenario 4 results (Fort Riley, KS).

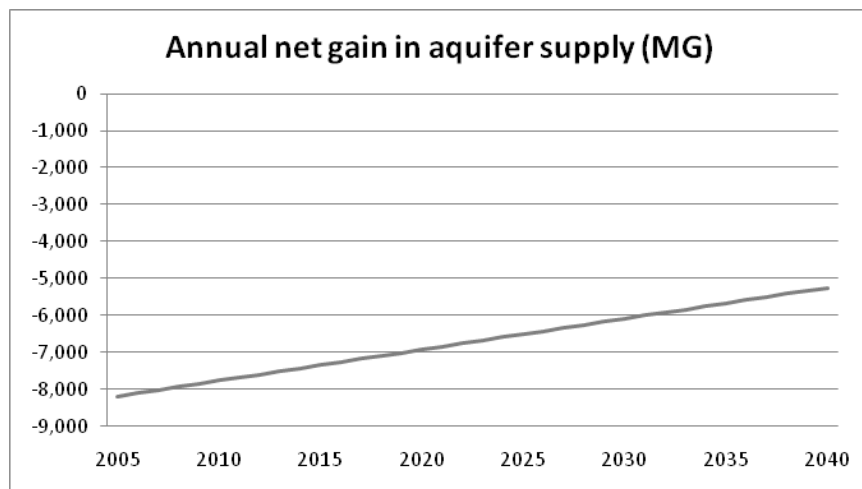


Figure 75. Scenario 5 results (Fort Riley, KS).

Table 34. Fort Riley regional scenario summary.

Fort Riley Region	2005 Baseline	2040 Scenario 1: Climate Change	2040 Scenario 2: Greater Demand	2040 Scenario 3: Status Quo	2040 Scenario 4: Water Efficiency	2040 Scenario 5: Upstream Diversion
Total aquifer recharge	10.42	9.37	10.21	10.21	10.21	9.40
Groundwater withdrawals by Fort Riley	2.00	2.92	3.85	2.92	2.75	2.92
Groundwater withdrawals by rest of region	30.83	20.86	30.83	20.86	10.48	20.86
Net change in aquifer supply	-22.41	-14.41	-24.47	-13.58	-3.03	-14.38

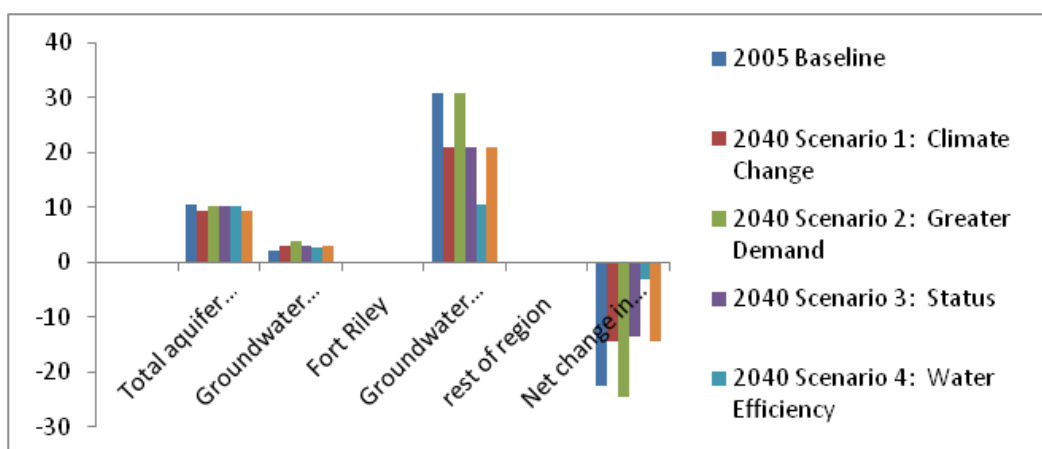


Figure 76. Fort Riley regional scenario summary.

The aquifer experiences a net annual decline in available aquifer supply under every single scenario, including the baseline (Table 34). The amount of that decline decreases in all but one scenario due to the anticipated population decline for the region. In the greater demand scenario — which stipulates the region’s population holding steady — the annual decline increases. Nonetheless, even with a smaller decline, most scenarios anticipate a net change in aquifer supply of roughly -14 MGD in 2040. This translates to an annual deficit of almost 5110 million gallons a year. If the region and Fort Riley work together to actively manage water demand, the expected deficit drops sharply to only -3.03 MGD or just over 1100 million gallons annually. While the region would still experience groundwater overdraft, such a step would significantly reduce the annual deficit and significantly increase the potential lifespan of the aquifer, for both Fort Riley and other regional users.

### Water sustainability assessment for the Fort Riley region

Fort Riley and the surrounding region currently overdraw water from the alluvial aquifers along the Republican River and will continue to do so for the foreseeable future. Eventually, these deficits will result in regional water scarcity. When regional water scarcity will occur is unknown. The amount of water actually contained within the aquifers is also unknown, therefore, it is unclear how severe the current water recharge deficit is. Further scientific studies are needed on alluvial aquifers along the Republican River to more accurately project available aquifer supply. Furthermore, the recharge rates that are used here are based on the most up-to-date studies available. However, knowledge of how the aquifers work is relatively limited. A major step to ensuring regional water sustainability is to create accurate models of aquifer storage, withdrawals, and recharge

with which to continue monitoring the water situation into the future. Without this knowledge, both Fort Riley and other regional water users are severely handicapped in their ability to foresee, plan for, and overcome water scarcity problems.

In the meantime, the region should pursue demand management. If the above analysis is correct, demand management alone cannot solve the region's water deficit, but it can greatly reduce it. The water reductions proposed in the water efficiency scenario are significant, but are achievable with off-the shelf technologies. The agriculture sector, in particular, will need support through the adoption of these technologies. As the biggest regional water user, agriculture has the potential to achieve the largest water use reductions. Although the technologies already exist to achieve these reductions, the effort necessary to adopt them can be a barrier. Fort Riley should work with local governments and other regional water users to help accelerate the adoption of water saving technologies and practices. Finally, if the results of further aquifer studies suggest that water scarcity is likely to be a problem in the future despite active demand management, further steps, such as induced aquifer recharge or the investigation of alternate sources, may need to be considered to ensure long-term water sustainability at Fort Riley and in the surrounding region.

## 11 Camp Shelby, Mississippi

Camp Shelby is a Mississippi Army National Guard training and maneuver site. Camp Shelby is located in southern Mississippi about 60 mi north of the gulf coast (Figure 77). The camp spans part of Perry and Forrest Counties and, except for the cantonment area, lies almost entirely within the DeSoto National Forest. Training is an important part of the installation's mission. The camp is the largest reserve component training site and the largest state owned training site in the United States.

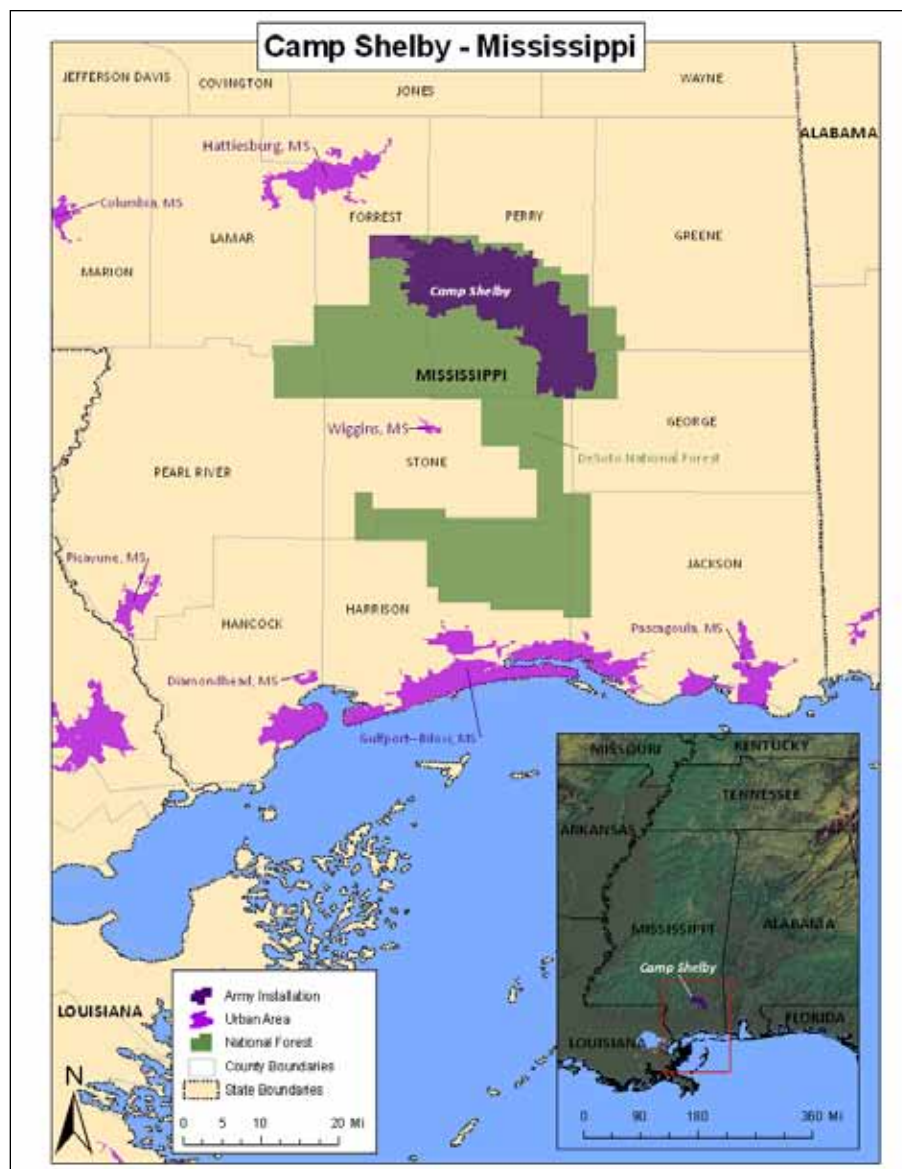


Figure 77. Location of Camp Shelby, MS.

This chapter provides an analysis of existing data on water availability and use at Camp Shelby and the surrounding region. Water use trends are projected out to 2040. A series of scenarios for water availability in 2040 are presented.

## **Regional characterization of Camp Shelby**

Both natural and human systems define the Camp Shelby region and shape the proposed water scenarios. Camp Shelby depends entirely on groundwater drawn from layers of sand under the camp for its water supply. Water supply and demand in neighboring counties that rely on the same sands or interconnected sands affect the camp's water availability.

### **Regional definition**

Currently, Camp Shelby's main water supply well draws from Upper Catahoula sands. Its back-up water supply well draws from Upper Hattiesburg sands — though the back-up well is almost never used (Dzeda 2010). These sands extend from southeastern Texas through southern Louisiana and Mississippi and into a small part of Alabama and Florida (Renken 1998). Locally, the aquifer system is called the Neogene aquifer system because the sands were deposited during that period (Roth and Patrick 2002).

The area is particularly difficult to geologically map because of vertical and lateral facies\* changes and to the absence of index fossils. The aquifer system is known to be complex and area sands are known to be interconnected (Roth and Patrick 2002). Without clear geological aquifer boundaries or unambiguous information on aquifer interconnectivity, defining a study region is problematic. For this study, it was assumed that wells within ten miles of the two Camp Shelby wells are likely to withdraw water from sands that are hydraulically connected to the same sands as Camp Shelby's wells. These include wells in Forrest, Lamar, and Perry Counties, MS. The HUC-12<sup>†</sup> level watersheds that intersect with the 10-mile radius drawn around Camp Shelby's wells create a regional watershed that is assumed to provide a land-surface recharge area for the wells (Figure 78). Forrest and Perry Counties are home to Camp Shelby, whereas Forrest and Lamar Counties are home to the Hattiesburg metropolitan area.

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\* A facies is a distinctive rock unit that forms under certain sedimentation conditions, reflecting a particular process or environment.

† 12-digit HUCs (hydrologic unit code) are sixth-level or subwatersheds.

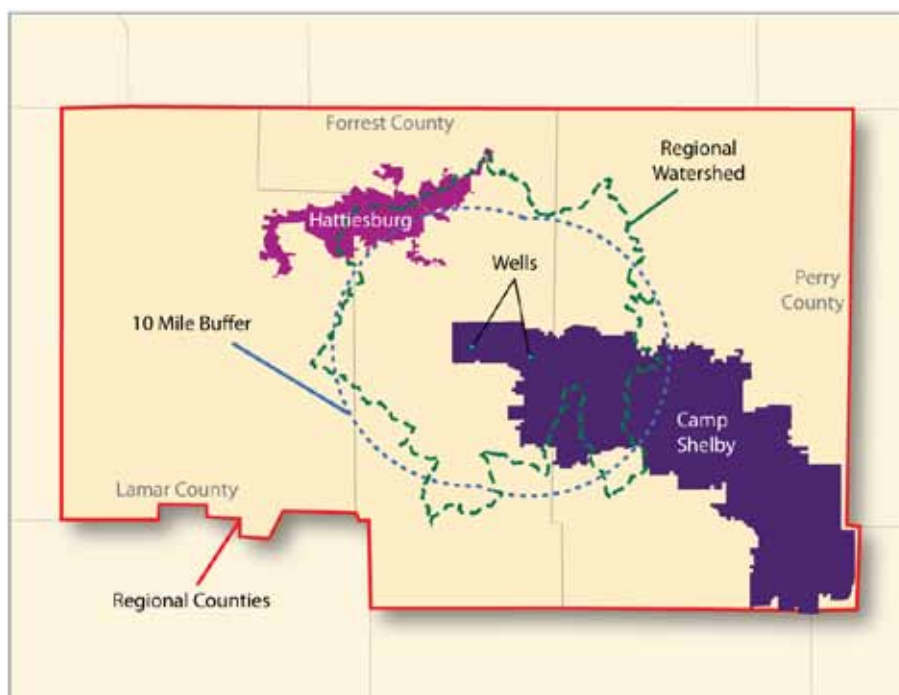


Figure 78. Camp Shelby, MS, study region.

Hattiesburg was included in the study region because the city contains the highest density of water users close to the installation. Thus, these three counties were chosen as the study region for this analysis.

### Demographic trends

Camp Shelby's population fluctuates as trainees come and go, but current maximum capacity on the installation is about 11,000 residents with an additional 2000 employees (Reid 2010). However, the actual number of people at Camp Shelby at any one time is generally far below this figure. Trainees and Soldiers come and go in small and large groups and stay for varying lengths of time.

The regional population projections prepared by the Mississippi Institutions of Higher Learning (Office of Policy Research and Planning 2008) were used to provide information on regional population. The projections were prepared using a cohort-component population model (by gender and race) with net migration. These projections are for the years 2015, 2020, and 2025. Estimates for years between projections were extrapolated and, for 2025-2040, estimated using earlier trends. The current population of the three-county region around Camp Shelby is about 143,000 (2009). By 2040 the expected population will increase to 192,500, — a 35

percent increase. The population increase may result in an increase in water use.

### **Water sources**

Camp Shelby depends entirely on groundwater. Public water systems in the three surrounding counties also rely entirely on groundwater, although agricultural users throughout the area and industrial users in Perry County use surface water as well (US Geological Survey 2005).

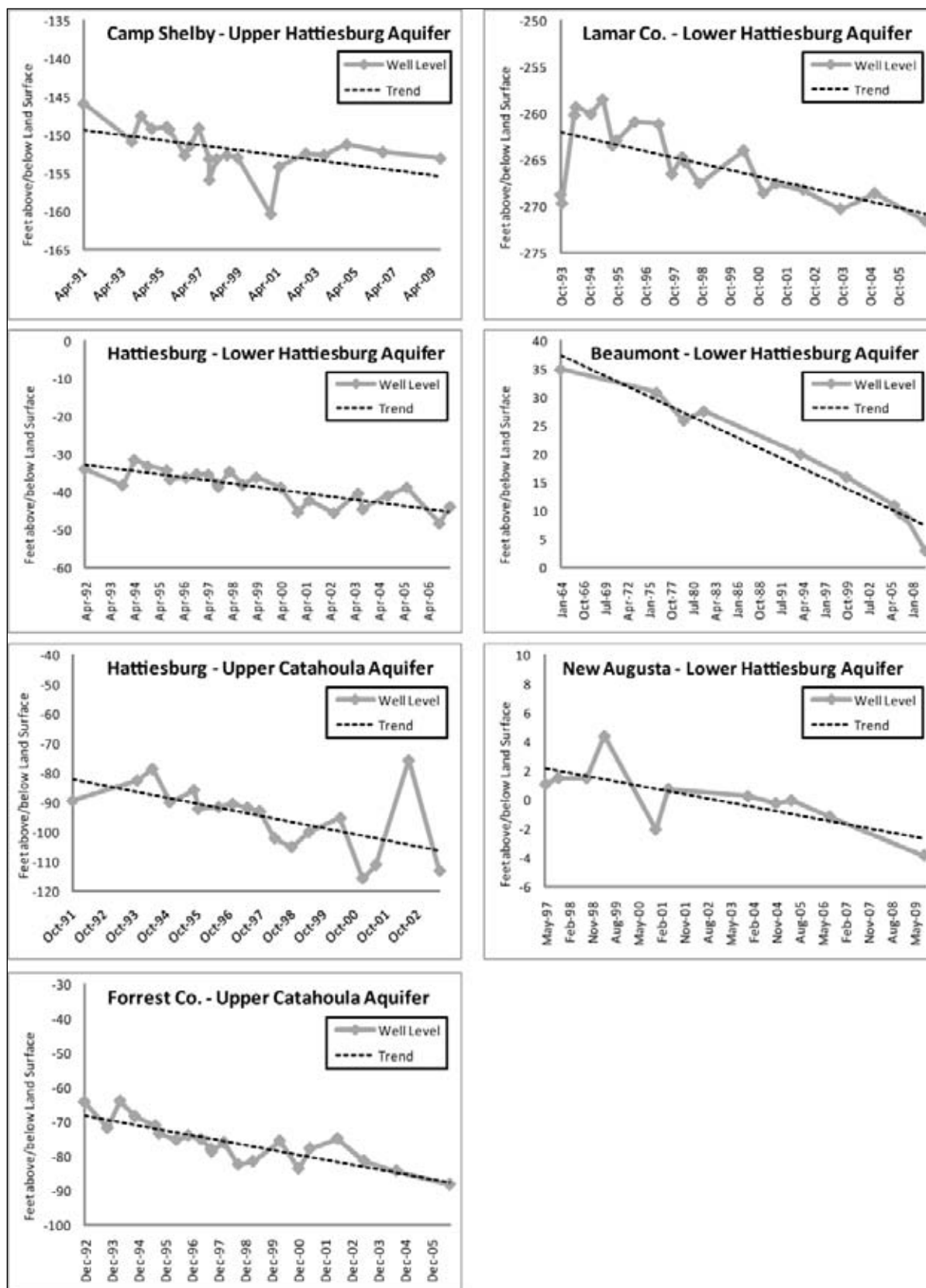
While the aquifer system has not been geologically mapped, it is possible to make an educated guess regarding the sand layer from which a well draws water by using borehole logs.\* Area users draw from a number of aquifers within the 10-mile radius identified around Camp Shelby's wells, including the following:

- Terrace Deposits
- Citronelle Formation
- Pascagoula Formation Sands
- Upper Hattiesburg Sands
- Lower Hattiesburg Sands
- Upper Catahoula Sands
- Lower Catahoula Sands
- Undifferentiated Miocene deposits.

Water level data are available for 141 wells however, the data are sparse (Mississippi Department of Environmental Quality 2010). Seven wells within the 10-mile radius have had water levels measured ten times or more, including one well owned by Camp Shelby. The eighth most commonly measured well had only six data points. Water level for these wells is measured as the depth of the non-pumping water level in feet relative to land surface (Figure 79). These wells draw from either the Hattiesburg or Upper Catahoula aquifers — the same aquifers tapped by the backup and primary water wells at Camp Shelby, respectively. Additionally, a number of public water systems have recently constructed new wells that draw from the Upper Catahoula Sands, the primary water source for both Camp Shelby and the city of Hattiesburg. Public suppliers prefer these sands as the water is easier to treat to potable standards than those of the Hattiesburg Sands (Hoffman 2010). While water level changes vary over time, with occasional increases in water levels likely from heavy rains, the overall trend for all seven wells is a slight decline in water levels.

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\* These sand layers extend for miles and are themselves difficult to correlate at times.



Source: Hoffman 2010).

Figure 79. Well water levels within 10 miles of Camp Shelby, MS.



Roth and Patrick (2002) examined well logs for aquifers in and around Camp Shelby and the entirety of Perry County. This study divided the county into three areas — northern, central, and southern — to aid in the identification of individual aquifers. Camp Shelby and the wells it draws from lie in the central portion of the study area. Roth and Patrick identified three separate aquifers for the study area — upper, middle, and lower — all of which have experienced some degree of drawdown or decline. In the upper aquifer in particular, where declines have occurred in the area around the northwestern portion of Camp Shelby, drawdown has been attributed to pumping at Camp Shelby. The study notes that “drawdowns are present throughout the study area. They tend to be centered near areas of activity such as Camp Shelby or highly populated areas” (Roth and Patrick 2002, p. 92). The study concludes that more data and research are needed to provide an understanding of area aquifers.

### **Climate**

Camp Shelby and the surrounding region are located in the pine belt along Mississippi’s coastal plain, a little inland from the gulf coast. The area has long, hot, humid summers, and mild winters — milder than other parts of the state due to the Gulf of Mexico. Proximity to the Gulf coast also means the area is at some risk from hurricanes as well. Temperatures for the area average around 48°F in January and 82°F in July. Average yearly rainfall is around 62 in. Precipitation tends to be slightly lower during summer and early fall (National Oceanic and Atmospheric Administration 2009).

Climate change is projected to increase temperatures, cause stronger, but possibly less frequent, storm events, increase evapotranspiration, and increase the occurrence and intensity of drought conditions throughout the region surrounding Camp Shelby. The most recent climate models predict an average increase in temperature of between 4.5 and 9°F for the Southeast by 2080. Additionally, while rainfall overall is expected to stay the same or decrease, the possibility of stronger storms heightens the risk of floods, especially along some portions of the Leaf River in the area (US Global Change Research Program 2009; The Earth Institute 2001; Twilley et al. 2001).

### **Topography and geology**

The East Gulf Coastal Plain in which Camp Shelby and the surrounding region are located is characterized by unconsolidated sediments, mostly sand and clay, with an occasional salt dome. Many of the geologic units

contain fresh water. The land is characterized by rolling hills, dissected by streams and swamps. Soils in the three counties are permeable and have infiltration rates ranging from moderate to very low with more soil on the moderate end of the spectrum. Approximately 63 percent of area precipitation, roughly 38 of the 62 in. the area receives annually, either evaporates or infiltrates into aquifers (Shows, Broussard, and Humphreys 1966). The remainder runs off into area streams.

Wells within a 10-mile radius of Camp Shelby generally draw from either the Catahoula formation or the Hattiesburg/Pascagoula formation. The former is the deepest aquifer with strata varying from stone/gravel to fine-grained sediments. In and around Forrest and Lamar Counties, the lithology is discontinuous and facies changes are common. The Hattiesburg/Pascagoula formation lies on top of the Catahoula formation and there is some contact between the two. The Hattiesburg/Pascagoula formation consists of both fine- and coarse-grained sediments, also with common facies changes. A limited number of wells also draw from the Citronelle formation, above the Hattiesburg, and from terrace deposits. Neither of these serve as a water source for the area today, although the Citronelle was extensively used in the past (Roth and Patrick 2002).

### **Land use**

The three-county area consists of 80 percent undeveloped land, including forest, grassland/scrub, and wetland. Much of this undeveloped land is part of DeSoto National Forest, which sprawls across the southern portions of Forrest and Perry Counties. The remaining land is split between agricultural and urban lands, with slightly more agricultural land (Multi-Resolution Land Characteristics Consortium).

Undeveloped land, particularly forest, was the only type of land cover to diminish in area between 1992 and 2001. While significant losses of undeveloped land can have negative effects on water infiltration, the amount and rate of this change is quite small.

### **Historic water demand**

The amount of groundwater used increased from 31.96 MGD in 2000 to 42.81 MGD in 2005 in the three counties in the Camp Shelby region (Table 35). Camp Shelby's use is included in the Forrest County withdrawals. In 2005, the installation used an average of 0.5 MGD, all derived from groundwater.

Table 35. Historic water use, Camp Shelby region (USGS Undated).

	1985		1990		1995		2000		2005	
	Overall	Ground	Overall	Ground	Overall	Ground	Overall	Ground	Overall	Ground
Forrest	25.65	19.25	24.07	19.82	41.78	14.21	53.39	13.47	32.36	18.98
Lamar	12.76	12.62	9.81	9.68	8.65	8.43	16.86	16.77	21.65	21.32
Perry	17.76	1.38	21.93	1.28	20.14	1.18	18.08	1.72	21.22	2.51
Total	56.17	33.25	55.81	30.78	70.57	23.82	88.33	31.96	75.23	42.81

Water withdrawals of any magnitude within Mississippi require a permit from the Office of Land and Water Resources\* (Mississippi Commission on Environmental Quality 2009). The law prohibits issuing a permit for any well the purpose of which is aquifer mining, unless that well is necessary to safeguard human life or property. Historically, water resources have been relatively abundant and few permits are denied. Drawdown has occurred in areas of high use, such as around Hattiesburg, but so far this has not resulted in any constraints on growth and future water use.

Camp Shelby's water use data are available from 2003 through November 2009. On average between 2003 and 2008, the installation used 0.49 MGD of water, with a slight declining trend over that time. Overall, installation use varied from a high of 0.67 MGD in 2004 to a low of 0.36 MGD in 2007.

## Developing the Camp Shelby regional model

Camp Shelby pumps all its water from local groundwater supplied via on-installation wells. Camp Shelby currently has two active wells, one for the main water supply and one as a backup. However, the backup well has not been used in several years as the main water supply well has been capable of meeting the entire installation demand. The following section examines the long-term supply available, focusing on local groundwater sources and long-term demand over the next 30 years.

### Water supply model

Local groundwater sources are quite complex and not well understood. It is unclear how much water is in the aquifers from which either of the wells draws or how those aquifers might be connected to other area aquifers. Therefore, it is not possible to estimate an actual quantity of water available to Camp Shelby or other regional users.

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\* Exceptions to permit requirements include domestic wells for one household and wells with a surface casing diameter of less than six inches.

Precipitation data are available to determine the amount of water that the area receives. The water can then runoff into streams and or the volume of water that evaporates. It is assumed that precipitation that does not flow into streams as runoff or that does not evaporate, infiltrates into the ground thereby recharging area aquifers. Using this information, it is possible to estimate annual recharge into area aquifers and project that estimate out into the future. Although this does not provide a full picture of area water supply, it allows for calculation of the amount of water infiltrated below the surface and thus *potential* aquifer recharge. For the purposes of this analysis it will be assumed that all infiltrated water comes from rainfall within the defined regional watershed (80).

### Drivers for Water Supply

1. *Rainfall.* Average yearly rainfall for the area is currently 62 in. (National Oceanic and Atmospheric Administration 2009).
2. *Runoff.* Average annual runoff is about 22 in. (Shows, Broussard, and Humphreys 1966) consistent with more recent national runoff estimates (Lettenmeir 2008).
3. *Evaporation.* Evaporation is estimated to have averaged 14.2 in. per year between 2007 and 2009.
4. *Potential recharge.* Using the above estimates to create a baseline recharge amount, ~25.8 in. of annual rainfall may recharge area aquifers.

Not all of the water that infiltrates below the land surface necessarily recharges area aquifers. Potential recharge may not actually recharge *any* aquifer. Water can flow laterally below the ground for long distances only to be discharged into surface water bodies elsewhere or to recharge aquifers elsewhere. Potential recharge may not recharge the proper aquifer. There are multiple layers of sand in the area that serve as aquifers. These aquifers are recharged from precipitation at different rates. Furthermore, water may or may not be able to flow easily from one part of one area of sand to another.

### Water demand projections

The water demand projection consists of two separate projections: a projection of water demand for all users from within the identified study region — the regional watershed plus Hattiesburg — and a projection of water demand for Camp Shelby itself. In each case, the projection establishes a baseline water withdrawal amount for the present and then combines that baseline data with information about expected growth to project withdrawal levels for 2040.

### *Regional water demand projection*

The water demand projection for the three-county region containing Camp Shelby uses USGS water-use data from 2005 as a baseline and incorporates population projections for the selected counties. The model focuses on groundwater demand only because Camp Shelby does not use direct surface water for supply. Groundwater use estimates for the entire county are weighted by the percentage of the county population living within the regional watershed or the city of Hattiesburg\* (Table 36).

**Table 36. Within region groundwater use breakdown (MGD).**

Public Supply	11.29
Domestic Self-Supplied	1.28
Industrial Self-Supplied	2.54
Irrigation	2.89
Power	0.93
Other	0.41
Total	19.34
Source: US Geological Survey 2005	

The regional water projection assumes that all public supply, residential, commercial and water loss will grow at the same rate as the population. Self-supplied industrial water use and water used for power production is combined. Power production, and the related water use, is expected to grow at the same rate as the population. However, it is assumed that any industrial growth that might occur in the three-county area over the coming years will tie into the public water supply network, thus no increase in water use is expected from the industrial self-supplied users. Agricultural and other land-intensive uses (livestock, aquaculture, and mining) are adjusted downward each year in proportion to the expected population growth rate to reflect loss of agricultural lands to residential land use. Table 37 lists the projected results for the larger region. Withdrawals are expected to grow by almost 27 percent (5.2 MGD) between 2005 and 2040.

**Table 37. Camp Shelby regional water demand projection results (MGD).**

	2005	2010	2015	2020	2025	2030	2035	2040
Forrest	16.02	16.77	17.14	17.75	18.04	18.73	19.26	19.79
Lamar	2.87	3.15	3.37	3.56	3.72	3.91	4.08	4.26
Perry*	0.45	0.45	0.47	0.47	0.47	0.47	0.48	0.48
Total	19.34	20.38	20.98	21.78	22.24	23.10	23.81	24.52

\*Note: Perry County's water demand is projected to grow over this period, but by less than 100,000 GPD.

\* The portion of people within the county that live within the study region is based on 2000 US census data that assumed that the number of people living in one part of the county versus another part of the county has stayed relatively constant over the last 10 years.

### *Camp Shelby Water Demand Projection*

The Camp Shelby Water Demand Projection uses data on historical water use, real property, planned building acquisition, and population projections for the installation to estimate future water use. Water use is estimated by building category (barracks, administration, storage). The installation does not have building water meters so building level water factors were used to predict the amount of water used per building — or in the case of barracks, per resident (Billings and Jennings 2008). Water use is adjusted downward for some buildings. These buildings are only used when trainees are at Camp Shelby and may not be used to full capacity. Local evapotranspiration is also taken into account to estimate irrigation water use.

Water-intensity use reductions in compliance with Executive Order 13514, which mandates a 2 percent reduction in water usage each year through 2020, are incorporated into the Camp Shelby water demand projection. All planned building acquisitions are assumed to occur between 2011 and 2015. This assumption was made because capital improvement plans generally have no more than a 5-year time horizon. Additionally, current population projections for the installation remain stable after 2014 (Headquarters Department of the Army 2009a). This results in projected water demand for the installation remaining stable from 2015 through 2040.

A baseline demand of 0.54 MGD was calculated for 2009, slightly higher than average installation use between 2003 and 2008 (0.49 MGD). Water demand is projected to increase considerably between 2009 and 2010 with the large increase in the number of trainees expected for Camp Shelby. After that increase, however, water demand is projected to remain relatively stable or, once the E.O. 13514 use reductions are factored in, to fall steadily through 2020. Without these reductions, Camp Shelby's demand is projected to be 0.84 MGD by 2040. With these reductions, the installation's demand is projected to be only 0.65 MGD in 2040 (Figure 80).

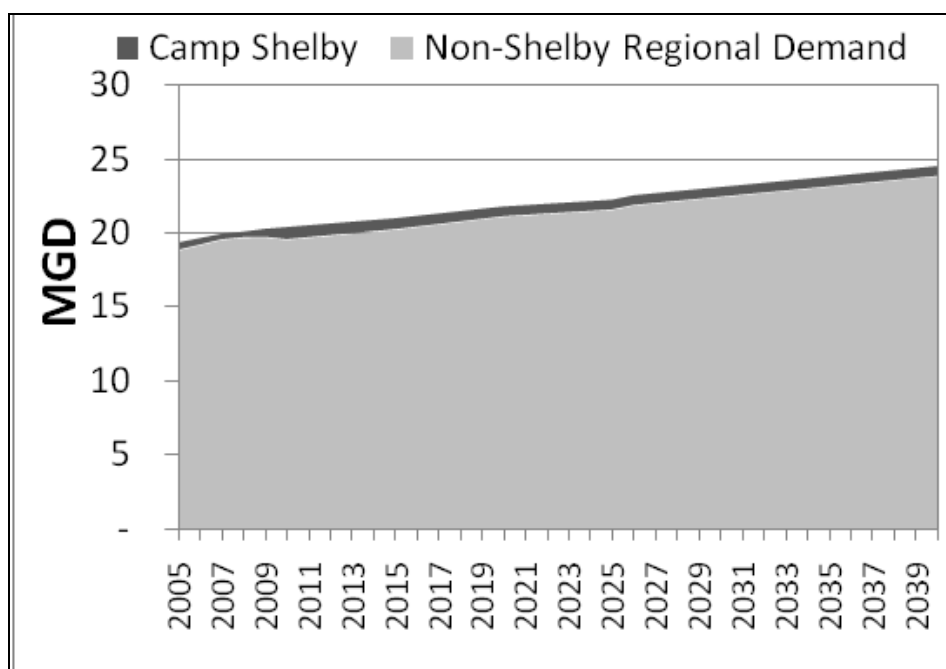


Figure 80. Camp Shelby, MS regional demand.

#### *Combined Demand Model Results*

Regional water demand is projected to grow by over 27 percent. If water efficiency best management practices were put into effect for the entire upstream region, the total withdrawals and consumptive use could potentially be significantly reduced.

### **Camp Shelby regional 2040 water availability scenarios**

A number of alternate future scenarios are presented for potential water recharge and future water demand. However, due to the lack of information on area groundwater supplies, the potential for regional water scarcity cannot be evaluated.

#### **Scenario 1 – Status quo**

Scenario 1 represents a water supply outcome in which current trends continue into the future bringing only gradual change to current water availability. The water demand projection previously described, which is based on current expected population and real property changes, is assumed to hold true. Climate change is assumed to affect the water situation only minimally. Compared with current conditions, there is a slight annual decrease in the amount of precipitation and slight increase in the annual evapotranspiration. Finally, Camp Shelby is expected to reduce water use by 2 percent per year between now and 2020.

## **Scenario 2 — Extreme climate change**

Scenario 2 explores a water future in which the magnitude of climate change that occurs is at the extreme end of the range of potential effects currently predicted for the region. Precipitation is expected to decrease and evapotranspiration to increase to a greater degree than in the previous scenario. Additionally, it is assumed that despite decreases in agricultural production related to on-going population growth, demand for water production for irrigation does not continue decreasing after 2015 as farmers are forced to use more water to contend with increasing temperatures. Water demand in the region is assumed to slightly increase to a higher level than in the status quo scenario. Other factors — installation water demand and annual water use reductions — remain the same as in Scenario 1.

## **Scenario 3 — Increased demand**

This scenario explores the possibility of more demand than is expected, both from the installation and from the greater region. In this scenario, it is assumed that installation demand increases without the mitigating effect of the annual 2 percent efficiency reductions. This change results in a 2040 installation water demand that is significantly higher than the demand projected in the status quo scenario. Regionally, population growth is expected to grow at a rate higher than that which is currently expected. Additionally, agricultural water demand is not expected to decrease after a certain point, either because of increases in water-use intensity (Scenario 2), or agricultural production failing to decrease despite on-going population growth, or both. Regional demand is also higher than in the status quo scenario. Other factors — precipitation and evapotranspiration — remain identical to the status quo scenario.

## **Scenario 4 — Water efficiency**

This scenario proposes a number of water conservation measures to be implemented at both the installation and regionally. By 2040, demand is lower than that expected in the status quo scenario, particularly at the regional level. Precipitation and evapotranspiration are again the same as in the status quo scenario. These conservation measures include increasing efficiency while reducing leaks and waste through cost-effective water-saving technologies, revised economic policies, and, appropriate state and local regulations. Sustainable management plans are programs created to help reduce water consumption based on changes in the water system.



Strategic intervention initiatives used in this scenario are a Public System Loss Management Program initiated in 2011, an Agricultural Water Conservation Program initiated in 2011, a Commercial/Industrial Water Conservation Program initiated in 2013, and a Residential Water Conservation Program initiated in 2019.

The Public System Water Loss Management Program consists of a 50 percent reduction in losses over a 2-year time frame through leak detection and remediation program. The Industrial Program consists of an approximate 39 percent reduction in use over 8 years with 90 percent market penetration through a water conservation program. The largest water savings could be realized in traditional heavy industries, saving nearly three-quarters of that sector's total current water use by replacing large volumes of cooling and process water with recycled and reclaimed water. Other industries that could save large quantities of water include commercial laundries and schools. The Residential Program estimates a 39 percent reduction in use in older homes starting in 2019 over 8 years with 90 percent market penetration. Even without improvements in technology, a water use reduction of almost 40 percent is estimated by replacing inefficient toilets, washing machines, showerheads, and dishwashers, and by reducing the leaks. In addition, a policy change requiring new homes to include ultra low flow toilets and showerheads is implemented in 2016 with 100 percent penetration because it is a building code requirement. The Agricultural Program consists of a 50 percent use reduction over 10 years starting in 2011 based on more efficient irrigation practices and overall reduced use.

### Scenario results

In all the scenarios (Table 38), including the baseline, significantly more water is projected to be available to potentially recharge an aquifer than is projected to be withdrawn. This is contrasted with data from area

Table 38. Scenario results.

	Potential Annual Recharge (MG)
Baseline	391.04
Status Quo — 2040	355.66
Extreme Climate Change - 2040	283.25
Rapid Population Growth - 2040	353.17
Water Efficiency Program - 2040	363.27

wells that show a slight decline. If the assumptions on the amount of water potentially available for recharge are not grossly inaccurate, then some of the potential recharge is reaching the aquifers or at least those aquifers tapped by area wells. If this is the case, then area aquifers could potentially exhibit problems with drawdown despite the plentiful rainfall.

Water supplies are expected to decline in the overall region from the baseline in the coming decades as climate change reduces overall precipitation and increases evapotranspiration. Water supply reductions are the severest in the extreme climate change scenario. Extreme climate change is a bigger threat to the region than the potential increased demand from a rapidly growing population.

The proposed water efficiency program is projected to reduce 2040 demand to an estimated 16.3 MGD. This is more than 3 MGD below the current estimated 19.7 MGD and almost 10 MGD below the estimated 2040 regional demand of 26.2 MGD. This lower demand is possible despite projected population growth over the coming 30 years. Implementing water efficiency measures can make a substantial difference in the amount of regional water required to meet user needs and to stretch the lifespan of current wells and, possibly, of the aquifers themselves.

### **Water sustainability assessment for the Camp Shelby region**

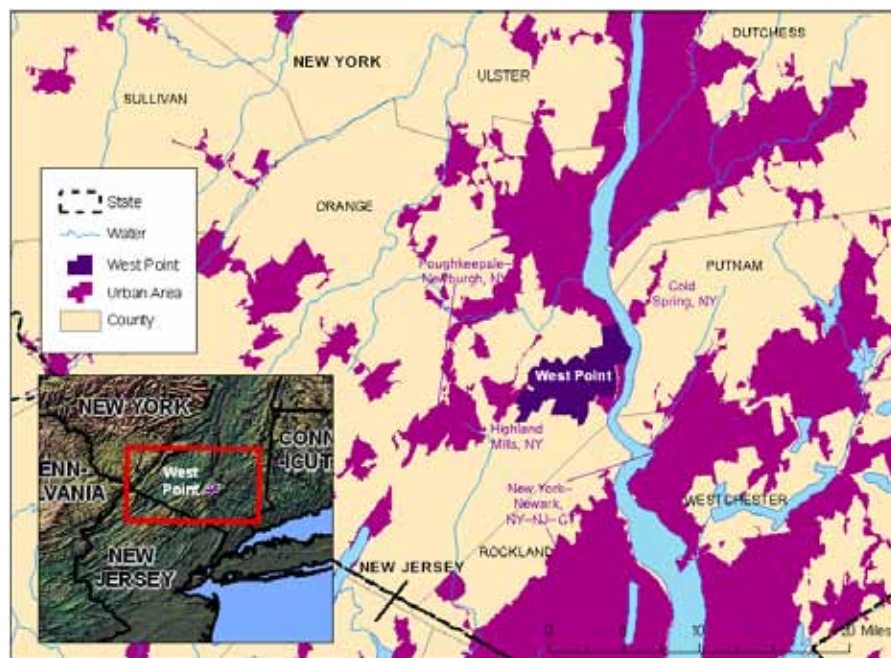
Due to the lack of information on groundwater resources in and around Camp Shelby and Hattiesburg, Mississippi, it is unclear how sustainable the water resources in the region are. Area wells are declining, but only slightly. The camp's main water supply well draws from an aquifer that is already tapped by the largest public supply user, Camp Shelby, and is increasingly being tapped by other public suppliers. It is clear that, as the climate changes over the coming decades, less water will be available to recharge the aquifer. However, the projected supply shows that the region will have plentiful water so long as precipitation is stored for future use, either in aquifers or elsewhere.

Demand management is often the easiest and least costly way for cities and regions to meet the future water needs of their populations. Facilitating precipitation recharge into area aquifers would also lengthen aquifer lifespan, perhaps indefinitely.

## 12 The US Military Academy at West Point, New York

The US Military Academy at West Point (USMA) is located on the western side of the Hudson River in southeastern New York, approximately 45 mi north of New York City and 100 mi south of Albany (Figure 81). Home of the US Corps of Cadets, the Academy's primary mission is "to train the Corps of Cadets, Army reservists, Reserve Officer Training Corps (ROTC) students, active duty units, and other government agencies who also conduct field training at West Point." Additionally, "West Point provides medical, administrative, commissary, post exchange, and other logistical support to military personnel, both active and retired" (Tetra Tech 2003).

Troops were first stationed at West Point in 1778. The Academy was established in 1802 with a mission to educate and train cadets to provide the nation with "leaders of character who serve the common defense (Tetra Tech 2003, p 1-9)." There are 423 historic housing units built between 1820 and 1949 on the Main Post that contribute to the National Historic Landmark District at West Point (US Army Corps of Engineers 2007 pp 4-5).



Source: USGS 2009

Figure 81. West Point boundaries and nearby features.

Base planning provides an indication of the relationship between history and change at West Point. Recently, the installation was authorized to convey 963 housing units, plus a hospital and additional acreage, for preservation and redevelopment by a private corporation. The plan calls for demolition of 196 units, renovation of 206 historical units, conversion of 174 historical units into “87 expanded historical homes,” and construction of 158 new units and a community center, partially through adaptive building reuse (US Army Corps of Engineers 2007, p ES-2).

### **Regional characterization of West Point\***

The installation consists of three areas: the 2500-acre cantonment area; the 14,000-acre outlying training area to the west; and Constitution Island, bounded by the Hudson except for the eastern border, which is defined by Metro-North railroad tracks. Except for the island, which is in Putnam County, the entire installation is located in Orange County, NY (Figure 81).

### **Demographic trends**

West Point began as an Army Corps of Engineers education and training facility authorized at just five officers and 10 cadets (US Military Academy 1909). While it began as an all-male institution, USMA began admitting women in 1976. It has evolved over time to fit a changing national climate and the needs of the Army. Today, the academy trains roughly 4400 cadets each year from every state and several foreign countries, with a faculty of 600 — both military and civilian (US Military Academy Undated).

The number of students and faculty on the installation is increasing as the US Military Academy Preparatory School moves from Fort Monmouth, NJ to West Point as part of 2005 Base Realignment and Closure program. The move is scheduled for 2011 (US Army Undated). The base population consists of between 10,000 and 11,000 students, members of the military, and civilians. While the installation is expected to grow slightly in the coming few years, with the move of the prep school and other Army transformation initiatives, the population of the garrison is expected to remain below 11,000 for the foreseeable future (Headquarters, Department of the Army 2009a).

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\* Unless otherwise noted, information in this section comes from Tetra Tech (2003).

Orange County, NY, had an estimated population of 383,532 in 2009. This is a 12.4 percent increase from the county's 2000 population and a 24.7 percent increase from 1990. This represents an annual growth rate of roughly 0.6 percent per year (US Census Bureau 2010). The county is expected to grow by over 100,000 people in the next 25 years. The 2035 population for Orange County is projected to be 493,079 (Program on Applied Demographics 2010).

### **Water sources**

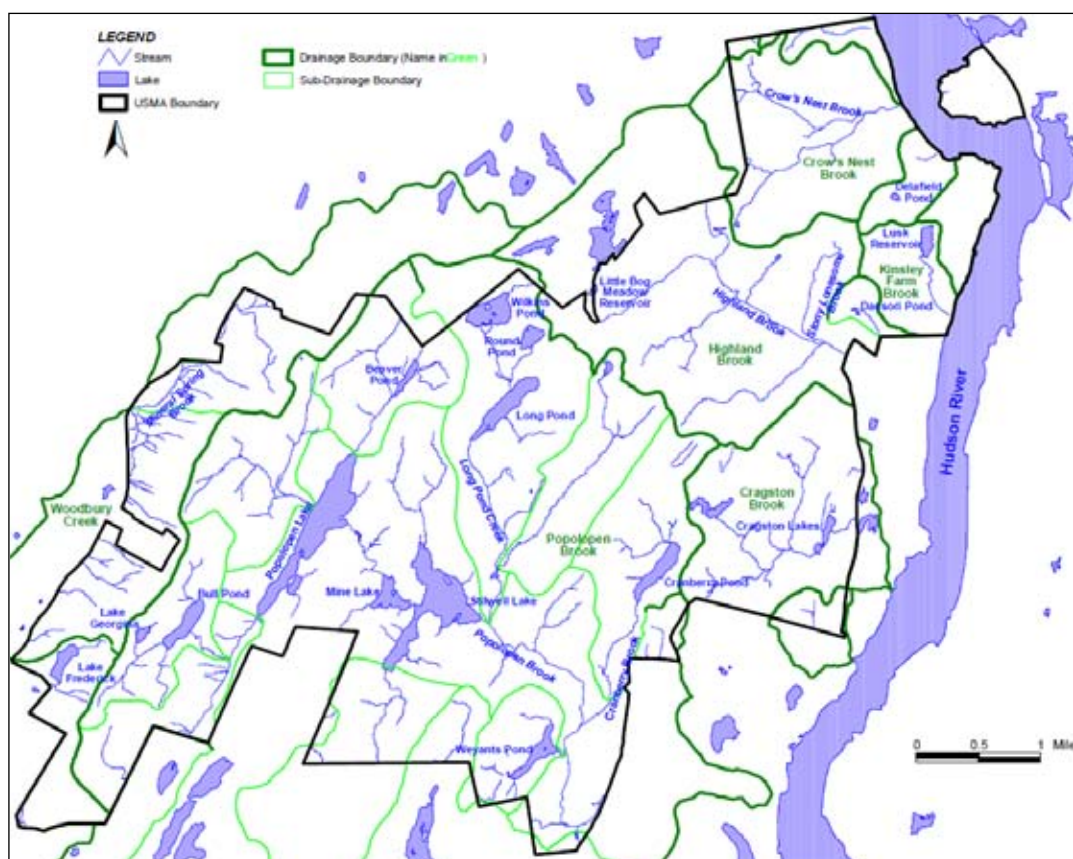
Water sources for West Point lie entirely within the boundaries of West Point. It is wise for installation planners to be aware of potential non-installation water demand increases due to increasing population in Orange County and other factors. This does not directly determine water availability on the installation but may affect demand\*. The flow onto the installation from outside its boundaries is minimal. The methods developed here use publicly available stream and well gage data. While publically available stream and well gage data are usually used to develop a Region Supply Model, those data are unavailable for West Point. However, it is still useful to understand the local water sources and to make some numerical adjustments to available water supply and demand estimates to test potential future water availability scenarios.

The study region is defined here as the installation itself. Regional demand outside the installation does not affect availability on the installation, thus excluding areas outside the installation from further consideration.

Many ponds and watercourses exist within the West Point boundaries, but not all are managed or contribute to water supply (Figure 82). However, there are significant water sources that contribute to the water supply through overflow that becomes runoff (US Military Academy, Directorate of Public Works 2005). The major surface drainage systems are the Popolopen Brook and Highland Brook systems, which eventually discharge into the Hudson River. The Popolopen system is also the major potable water source (Tetra Tech 2007).

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\* The safe yield study was prompted by requests for water from West Point's supply from outside the post when local sources became contaminated.



Source: Tetra Tech 2007.

Figure 82. The surface water systems of West Point, NY.

According to installation water provider terms of service, “the West Point Water Treatment System consists of three water treatment plants (Lusk, Stony Lonesome and Camp Buckner) and one separate well system (Round Pond) that services West Point” (US Military Academy undated). The Round Pond well system is not a major water source and only shallow wells are possible in this region so it was not considered in this study (Tetra Tech 2007).

Lusk Water Plant, built in 1932, can supply 3 MGD (US Military Academy Undated). A gravity pipeline from Popolopen Brook to Lusk Reservoir supplies the plant. Water is pumped from Stillwell Lake to Stony Lonesome Treatment Plant (Tetra Tech 2007). The plant was constructed in 1970 and can process a design capacity of 2 MGD (US Military Academy Undated). “The Camp Buckner Water Plant services both Camp Buckner and Camp Natural Bridge and went online in 1995. [It] draws water from Popolopen Lake and has a full operational capacity of 0.8 MGD” (US Military Academy Undated) (Table 39).

Table 39. Summary of major water bodies and stream (Source: Tetra Tech 2007).

Water Body or Stream	Description
Long Pond	Leased to Town of Highlands for recreation
Popolopen Brook	Outlet stream of Stillwell Lake; supply for Lusk Reservoir
Popolopen Lake	Large, popular recreation lake for West Point; supports cadet field training at Camps Buckner and Natural Bridge for which it provides drinking water
Queensboro Brook	Small portion on USMA property; Queensboro watershed is location for Palisades Interstate Park Commission (PIPC) withdrawal agreement mentioned in the scenarios section
Mine Lake	It's outlet serves as Stillwell Lake's major inlet

### Climate

Area climate is considered humid continental, with variable weather and large seasonal temperature changes (New York State Climate Office Undated). Summers are warm and humid, whereas winters are snowy and cold. Three weather patterns influence daily weather at West Point:

- Warm, humid air that flows into the area (the “Bermuda High”)
- Cold air flowing into the area from the Hudson Bay
- Cool, cloudy, and damp air flows from the north Atlantic.

Temperatures average 86 F in July and 27 F in January, and plentiful annual precipitation averages just over 48 in. West Point experiences both thunderstorms and tornadoes, though the latter occur with less frequency.

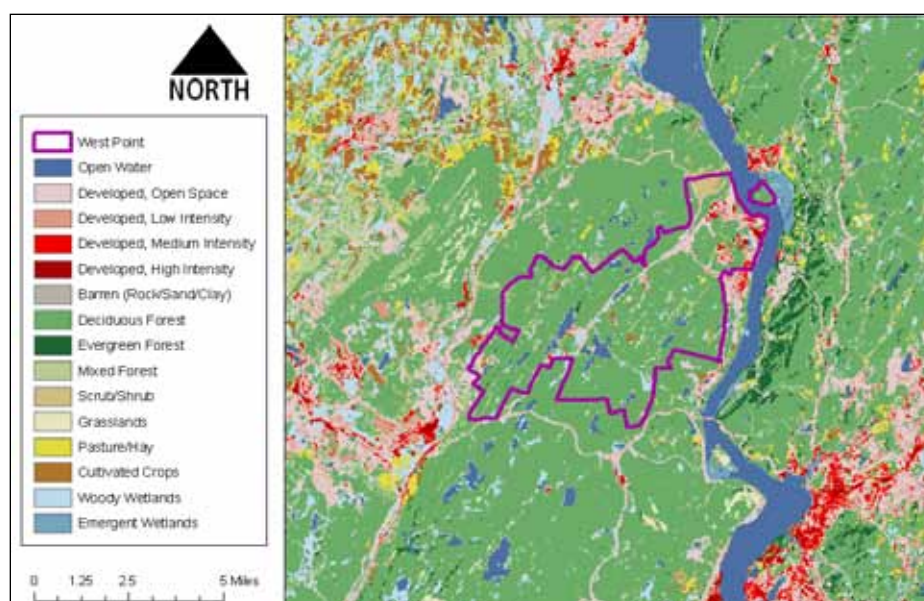
### Geology, topography, and soils

West Point lies in the Hudson Highlands, a low mountain range that reaches from Pennsylvania northeast to Massachusetts. The installation is characterized by steep, rocky hillsides with exposed bedrock, mostly metamorphic. The topography across the installation varies greatly. Elevations vary from zero to 1,000 ft above sea level. Slopes vary from zero to 70 percent (Tetra Tech 2007). Most of the installation's soils are categorized as well-drained or excessively well-drained though some soils in low-lying areas drain poorly and create wetlands. Water moves quickly over the sloping topography.

### Land cover and use

The most prominent land cover is forest (Figure 83). This is partly due to the Hudson Highlands. Several protected areas, Black Rock Forest and Storm King State Park to the north of the installation and Mountain/Harriman State Park to the south, provide forested areas in close proximity to the installation.





Source: Multi-Resolution Land Characteristics Consortium 2001.

**Figure 83. Landcover in and around West Point.**

The installation is also surrounded by sizeable amounts of both developed and farm lands. The combined Poughkeepsie-Newburgh metropolitan area lies to the north and west of the installation. The New York metropolitan area lies to the southeast of the installation, across the Hudson. Developed lands tend to be residential and commercial with occasional light industrial uses. There is a “moderate and increasing” level of residential development along the installation’s western border (Tetra Tech 2007). On the installation itself, the cantonment area occupies the northwest area along the Hudson, whereas a large portion of the remainder is open range land. Training areas comprise approximately 14,000 acres.

### **Historic water demand**

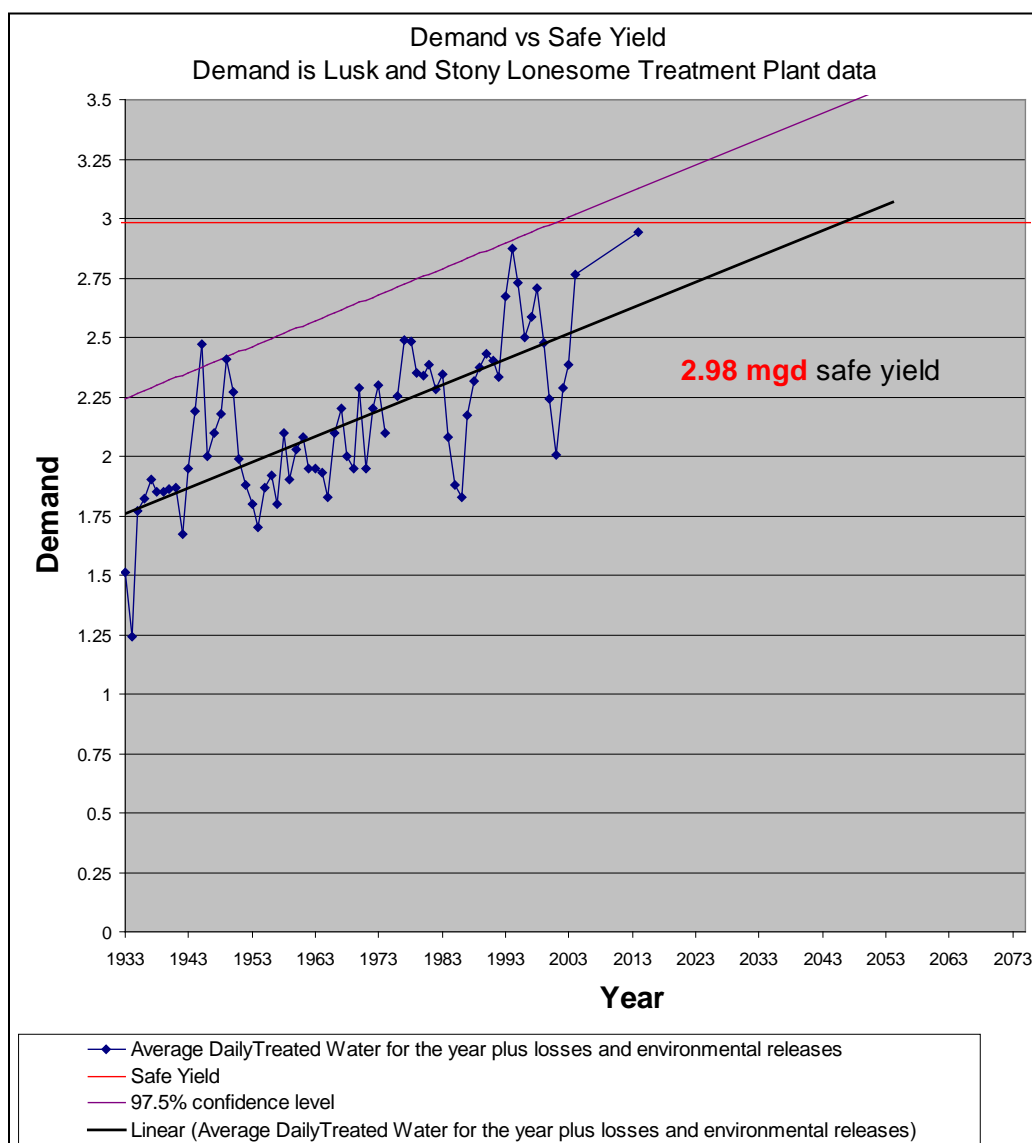
USMA West Point’s historical water demand data were not available for this study. However, secondary data are available for a number of years from the Safe Yield study for the Popolopen watershed (USMA DPW 2005). Additionally, water demand for FY07 is available from the 2007 USMA Water Management Plan, and figures for 2009 water demand were provided by the installation (Jones 2009) (Table 40).

Installation water demand between 1933 and 2004 has varied, e.g., up to 0.535 MGD of difference (USMA 2005). However, overall (Figure 84) water use on the installation has been increasing over the years. It has not dropped below a 2.0 MGD average since the 1980s. Most demand has been above 2.5 MGD since the 1990s.



Table 40. US Military Academy, West Point, NY  
historic demand.

Year	MGD
2001-2003 avg.*	2.32
2004	2.76
2007	2.58
2009	2.97
*May not include Camp Buckner use	



Source: USMA DPW 2005.

Figure 84. Water demand and additional information from Safe Yield study.

The 2007 USMA Water Management Plan also includes an audit of the installation's water use, breaking use into five categories: Housing, Commercial, Irrigation, Leaks/Losses/ Unaccounted for Water (UAW), and Industrial. The data from this audit provide important insight into current

water use patterns and was used in the calibration of the Installation Demand Model. One barrier to using these data, however, was that the study appears to report two sets of results for this water audit (Table 41).

The second set of results was used for the following analysis for two reasons. First, the second set of results sum to 100 percent, whereas the first set does not. Also, the first set of results for the Commercial, Irrigation, and Losses categories are unlikely:

- Commercial facilities in the 2007 plan include all of the “administrative buildings, dining halls, hospitals, schools, etc.” It is highly unlikely that these types of facilities would use only 2 percent of an installation’s treated water. At every other installation presented in this report, administrative facilities alone used at least 13 percent of total water, not including water use for dining facilities, hospitals, and some schools.
- According to West Point’s real property data, the installation has over 5100 acres of irrigated land. Even if the installation applied only one in. of water to each of these 5100 acres over the course of a year, it would require over 380 thousand KGD. By comparison, 1.6 percent of West Point’s 2007 water consumption is equivalent to less than 44 KGD.
- Three percent water loss in the water distribution system for any water utility is exceptionally low. The average water loss level in developed countries is 15 percent, with 40 percent water loss not uncommon, 10 to 12 percent is considered acceptable, and below 10 considered pretty good (Kingdom, Liemberger, and Marin 2006; Lahlou 2001; and MTAS 2000). Three percent is very low in general, but is even more so for a water system as old as West Point’s.

For these reasons, the second set of results were used later in this analysis to better estimate current water demand and project future installation water demand.

**Table 41. Alternate water audit results from 2007 US Military Academy, West Point, NY Water Management Plan.**

	Results #1	Results #2
Housing	29.0%	29.47%
Commercial	2.0%	20.69%
Irrigation	1.6%	26.67%
Losses/Leaks/UAW	3.0%	19.37%
Industrial	4.0%	4.00%
Total	40.0%	100.00%

## Developing the West Point regional model

Existing regional water availability and use data are examined to project these trends out to 2040. A series of alternate future scenarios for water availability in 2040 were developed and evaluated.

### Water supply model

In the absence of regional gage data, the safe yield and demand estimates from the DPW study were incorporated and altered to test multiple scenarios described below. Five estimated water flows are common to each scenario. Although the specific factors that contribute to their exact amounts vary from one to the next, their underlying premises remain the same (Table 42). This analysis allows for comparison of water availability versus demand across a range of future conditions.

### Installation water demand model

The following presents the detailed assumptions and inputs of the Installation Demand Model, which uses West Point real property data and average water use by structure type to forecast future consumption.

Table 42. Water flows shown in each scenario (MGD).

Flow Name	Description
Safe Yield Estimate — 2005 Study	The safe yield estimate cited directly from the <i>Analysis of Safe Yield Opportunities</i> (USMA DPW 2005)
Safe Yield Estimate — [named modification]	The safe yield estimate modified by increased runoff due to climate change, sometimes paired with reduction in Palisades Interstate Park Commission (PIPC) flows
Demand Estimate — Installation Demand Model (IDM) [named modification]	USMA flow demand as estimated by the Installation Demand Model, sometimes adjusted as noted in the scenario explanations
Demand Estimate — 2005 Study + [named modification]	USMA flow demand as estimated in the Safe Yield study, sometimes adjusted as noted in the scenario explanations
Demand Estimate — 2005 Study Adjusted + [named modification]	USMA flow demand as estimated in the Safe Yield study, but adjusted to use water treatment volume from Feb. 2009 to Feb. 2010, derived from Lusk and Stony Lonesome data provided by DPW — also sometimes adjusted as noted in the scenario explanations Jones 2010)

### *Baseline Development*

The water use baseline was determined as a first step to projecting future water demand at West Point. This baseline was constructed using the most recent data available for the various water inputs —mostly 2008 and 2009 data — and then calibrated to approximate West Point’s current water demand (US Military Academy 2007) (Tables 42 and 43).

The Barracks Units is roughly equivalent to the number of spaces in dormitories for individual students and Housing Units, to the number of family housing units. Both of these values are derived from real property data provided by West Point DPW and IMCOM (Jones 2010 and HQDA 2009b). Military Stationed, Transient Population, Dependents, and Civilian Workforce are derived from the Army Stationing and Installation Plan (HQDA 2009a).

Deployment Factor is an estimate representing the average occupancy level of existing housing on-installation. On most installations, vacancy rates are determined by deployment. Although the USMA is a college, a significant amount of training occurs during the summer, and it is assumed that vacancy rates over the course of an entire year are relatively low — hence the use of 90 percent for deployment factor. The growth factors below, Industrial/Maintenance through High Water Use Facilities, are all set to a default of 1.00.

Table 43. West Point installation water demand model inputs.

West Point - Projection Input	Baseline
Barracks Units	6,399
Housing Units	996
Military Stationed	6,191
Transient Population	5
Dependents	2,205
Civilian Workforce	4,241
Typical Military Family Size	1.74
Deployment Factor: Family Housing	0.90
Deployment Factor: Barracks	0.90
Industrial/Maintenance Factor	1.00
Storage Growth Factor	1.00
High Water Use Facilities Factor	1.00
Irrigated Land Factor	1.80
ET (Moisture Deficit)	0.98
Losses Factor	0.19

“ET” is a moisture deficit factor that represents region-specific evapotranspiration. The value used here is 0.98 in. This is an estimate of annual evaporation using monthly averages for Orange County. This data were obtained from the Safe Yield Study performed for Popolopen Brook Watershed by the installation in 2005 (USMA DPW 2005).

The actual amount of water used for irrigation at West Point was calculated using data from the 2007 Water Management Plan and estimated to average 0.69 MGD (USMA 2007). The water use factor was then adjusted upward to calibrate projected water irrigation demand for the baseline year to roughly that level — 0.68 MGD (Table 44). Several reasons, taken singularly or in combination, may explain why the model did not calculate irrigation water use accurately: (1) the input number of acres irrigated from the real property dataset is inaccurate, (2) the moisture deficit estimate is inaccurate, or (3) USMA may be watering areas beyond the strict minimum amount of water needed to replace moisture lost to evapotranspiration.

“Losses” factor represents the percentage of water that is either lost in transit through leaking pipes or is otherwise unaccounted. Approximately 19.37 percent of water treated is unaccounted for. Baseline consumption is given in gallons per unit per day (gpud) by type of real estate. The unit is usually the building, although in some cases, the unit is per capita (family housing, barracks) or another metric (Table 45).

Table 44. West Point water usage estimated baseline.

West Point - Usage (MGD)	Baseline
Family Housing	0.16
Barracks	0.58
Dependent Schools	0.02
Medical	0.02
Industrial/Maintenance	0.08
Lodging	0.12
Administration/Moderate Users	0.24
Community and Commercial: Non-food related	0.07
Community and Commercial: Food-related	0.01
Storage	0.00
High Water Use Facilities	0.05
Irrigated/Improved Land	0.68
Other Uses	0.00
Losses	0.39
<b>Baseline Annual Average (MGD)</b>	<b>2.41</b>

Table 45. Baseline water consumption by unit.

West Point - Consumption (gpud)	Baseline
Family Housing	101
Barracks	101
Dependent Schools	25
Medical	1,236
Industrial/Maintenance	700
Lodging	150
Admin/Moderate Users	1,204
Community and Commercial: Non-food related	629
Community and Commercial: Food-related	906
Storage	10
High Water Use Facilities	900

The 101 gallons per capita per day water use estimate for housing and barracks is based on reported numbers for average per capita residential water use in cities across the nation (Walton 2010). Other factors are calculated from water use estimates from the installation itself, or derived from rules of thumb (Billings and Jones 2008). “High water use facilities” are based on a general rule of thumb because this category is so varied. Altogether, this resulted in a baseline annual average usage estimate of 2.41 MGD (Table 44). This estimate is slightly lower than West Point’s 2.58 MGD water use for 2007 and 2.97 MGD use for 2009, but it is still reasonably close to actual use (USMA 2007 and Jones 2010).\*

#### *Installation Demand Model Results*

The baseline described above was used to project the demand for USMA out to 2040. The demand model uses the datasets already described to forecast demand. Some of the datasets — the ASIP, for instance — already contain projections for future years. These projections are incorporated into the model. The major dataset that lacks information about future change is the real property dataset for construction and demolition.

The “baseline annual average” represents projected water demand if water use were to continue to follow current trends (Figure 85). “Annual MGD w/efficiency” represents the projected water demand if the water efficiency targets of EO 13514 were achieved.

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\* Data for installation water use was not available for 2008. Estimated use for 2009 does not include Camp Buckner.

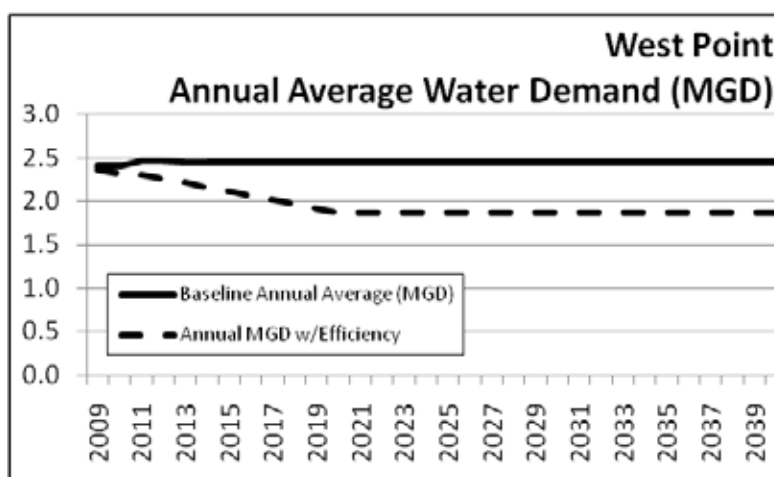


Figure 85. Installation demand model results, West Point, NY.

## West Point 2040 water availability scenarios

### Scenario 1 – High emissions climate change

Scenario 1 poses a potential future in which climate change impacts occur along the more extreme end of the spectrum of potential effects. After averaging the effects of 24 different climate change models, Milly et al. (2005) estimates a 2- to 5-percent median increase in runoff, defined as the difference between precipitation and evaporation, for much of the eastern United States, including the West Point region of New York (as cited in Lettenmeir et al. 2009). For these reasons, in Scenario 1, it is assumed that runoff increases by 5 percent.

Increased runoff could mean increased water volume for the streams and lakes of West Point. This volume could support an increase of available water. For this analysis, it is assumed that the safe yield estimate is a proxy for actual water availability under current conditions. The future runoff increase is added to the current water availability estimate — the safe yield — to develop a future water availability estimate.

Installation water use practices are assumed to remain the same as they are at present so installation demand is assumed to be equivalent to the projected demand from the Installation Demand Model. On the supply side the safe yield increased by 5 percent to account for the effect of extreme climate change. On the demand side, water demand has been increasing faster than previously projected (Figure 86).

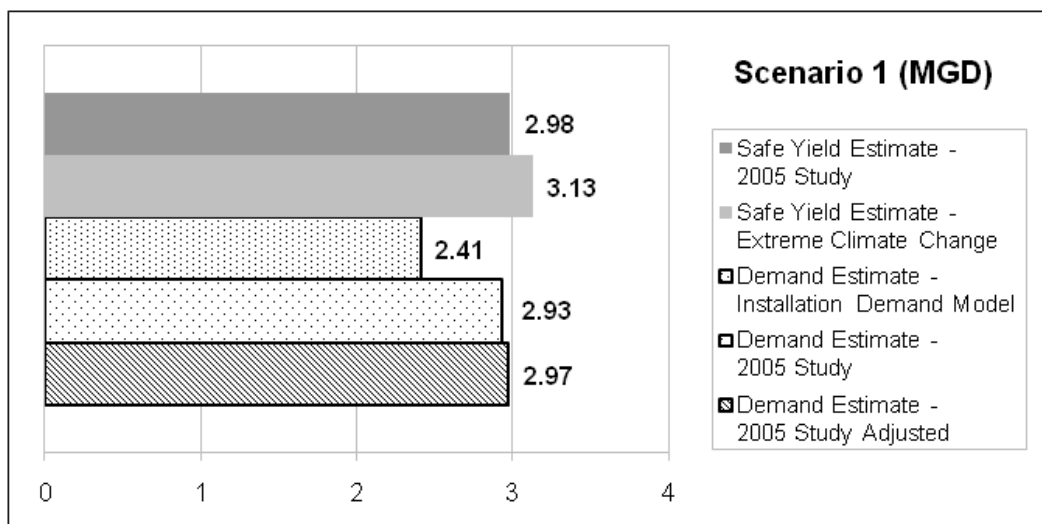


Figure 86. Scenario 1 results (West Point, NY).

Stormwater runoff is increased in a hilly region like West Point's. This could exacerbate erosion and decrease water quality. Chemicals, nutrients, and solids could be carried into water bodies more frequently. Under lower runoff conditions, they may generally have more time to infiltrate into the soil, where some filtering occurs. If the increase comes in the form of higher peak runoff from more intense storms, erosion could be a bigger concern. Runoff from the first minutes of rainfall is usually the dirtiest (the "first flush") (Debo 2009). Therefore, while climate change may increase the quantity of available water, it may also decrease the quality of that water.

### Scenario 2 – Status quo

Scenario 2 is a "status quo" scenario. It explores the possibility that current trends will continue. Instead of assuming extreme climate change impacts that result in a 5-percent increase in runoff, this scenario assumes moderate climate change impacts with a 2-percent runoff increase. On the demand side, water use practices again remain unchanged, resulting in the same demand estimates as in the previous scenario (Figure 87)

### Scenario 3 – Palisades Interstate Park Commission supply reduction

Currently, the Palisades Interstate Park Commission (PIPC) provides a minimum of 300,000 gallons per day (0.3 MGD) to the Lusk Reservoir. During a drought, this water transfer can be, briefly, the primary source of water for the reservoir (USMA DPW 2005). What if this PIPC amount were not available?



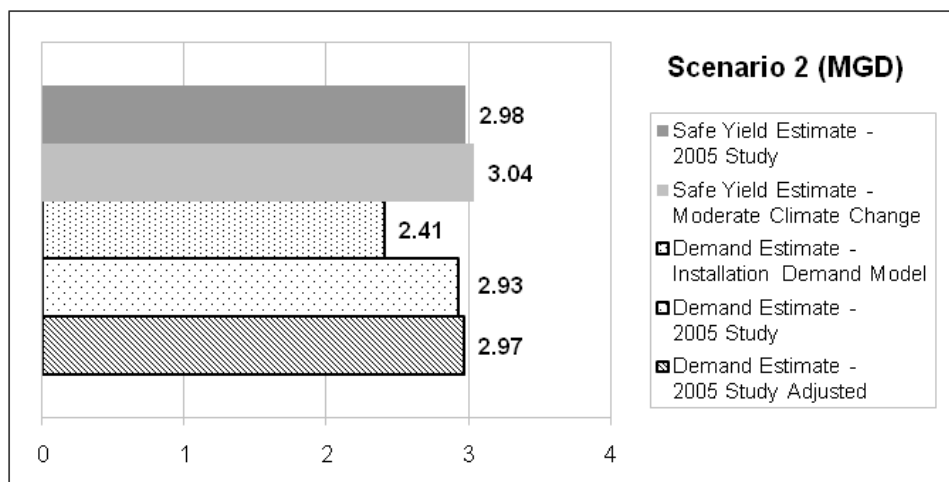


Figure 87. Scenario 2 results (West Point, NY).

Water availability would be reduced by 0.3 MGD, the amount of water that can safely be withdrawn from the watershed. This reduction is applied directly to both the standard safe yield estimate and the estimate with moderate climate change (Figure 88). Again, water demand is set equivalent to the results of the baseline water demand model in Scenarios 1 and 2.

#### Scenario 4 – Increased demand due to planned construction

The water demand projection from the safe-yield study accounted for the planned addition of several new water using facilities that in total are estimated to use 0.048 MGD. An additional 15 new facilities would be constructed in the coming years, but the scenario assumes that these facilities would pose no significant increase in water use, although fixtures and equipment are to be included, because any increase will be offset by decreases elsewhere (USMA DPW 2005).

Many of these unquantified projects do not appear to use water, such as a road, a parking structure, or building renovations. However, no offsets are provided.

Scenario 4 explores the effect on demand if these 15 facilities actually use the same amount of water as the other new structures, i.e., 0.048 MGD (Figure 89)

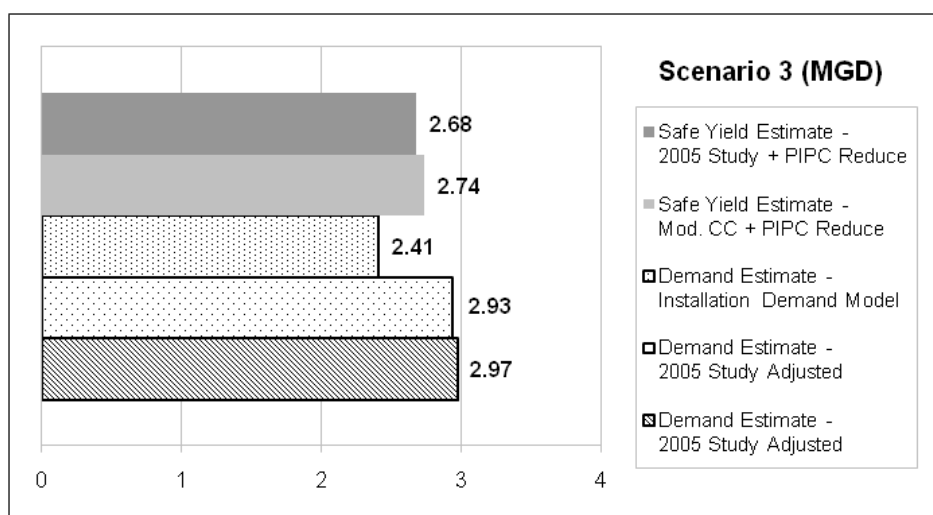


Figure 88. Scenario 3 results (West Point, NY).

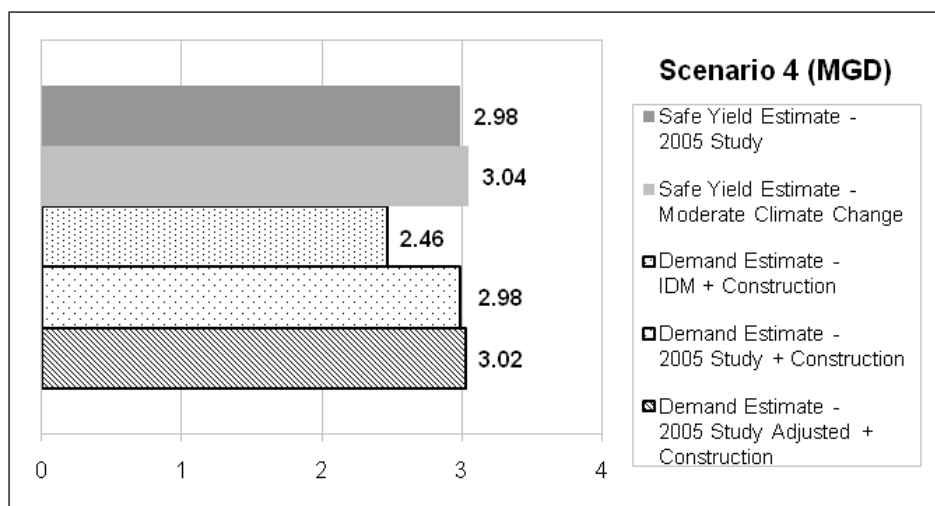


Figure 89. Scenario 4 results (West Point, NY).

### Scenario 5 – Increased efficiency – irrigation and losses

To simulate possible water reductions, Scenario 5 assumes that leak surveys continue and additional efforts are made to track and reduce uncategorized water. The Installation Demand Model “Loss Factor” was adjusted down, from 19 to 7 percent, and the “Irrigated Land” factor was adjusted down, from 1.8 to 1 (Figure 90). The reduction magnitude in MGD from the Installation Demand Model estimate was then applied to the 2005 Study and 2005 Study Adjusted estimates for comparison.

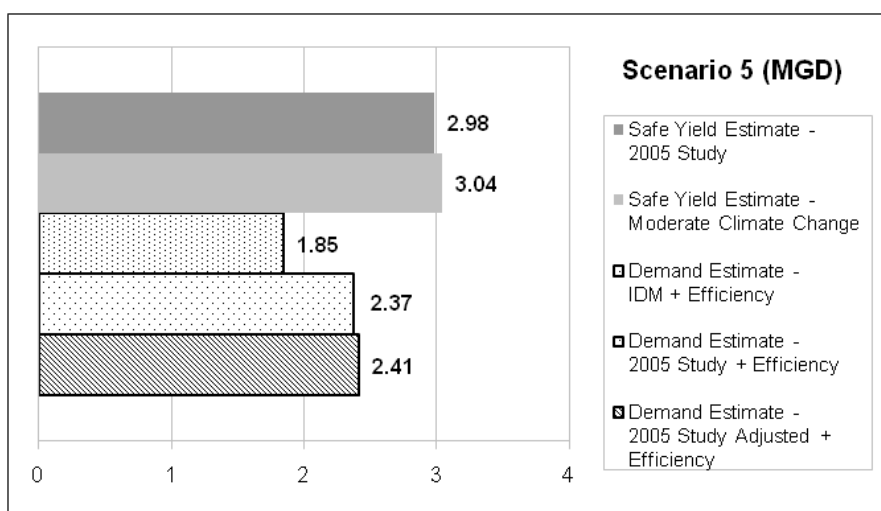


Figure 90. Scenario 5 results for West Point, NY.

## Conclusions

“Safe yield” does not necessarily mean “sustainable yield.” For all the scenarios, supply and demand hover around equilibrium, but they still appear very close, and peak demand can be higher than these averages. The largest changes occur in Scenario 5 with the implementation of best conservation management practices. Even though many efficiency measures are not cost effective (USMA 2007), they will be needed in the future if demand is greater than the projection, particularly if current demand exceeds the safe yield.

Although a recent leak detection survey was performed, continued water loss could be investigated as to where these losses were occurring and then repaired (USMA 2007). Monitoring water use more closely and installing and monitoring stream gages would provide additional means to collect data and determine where water can be conserved. Over time, non-potable water could be used for all irrigation activities. EO 13514 encourages installations to identify, promote, and implement water reuse strategies consistent with state law. For example, at Fort Hood, 0.2 MGD on average of non-potable reuse water is used to feed the Clear Creek Golf Course. Projects like these can be cost effective. The simple payback period in this case is only 3 years for the capital costs (Scholze 2009).

West Point trains the Army’s future leaders. The presence of sustainable water systems would serve to imprint them as responsible options. This opportunity is unique to USMA, seems consistent with West Point’s mission, and could cause a future ripple effect in the Army’s resource management practices as water issues become increasingly more important to mission sustainability.

## 13 Conclusions

Water security is becoming a significant issue across the US Army installations, the communities that surround them, and the regions in which they are located are not water secure. Changes in water demand because of population variation from internal changes or migration, climate change, and ecosystem requirements will all affect the ability of the Army to maintain and operate its installations. Limiting conservation efforts to only meeting mandated water use targets is insufficient for installations to be water secure. It is imperative that the Army develop a set of goals, objectives, strategies, performance measures, and commit resources to prevent water scarcity from degrading its mission.

Another complicating factor is that water is a resource that recognizes no boundaries —installation, municipal, county, region, state, and national— other than its own, that of watershed or sub-surface aquifer. People intervene in the natural hydraulic systems through inter-basin transfers, the movement of “virtual water” from one water region to another in products, and the increased withdrawals by water-intense industries. Planning for water sustainability is a regional issue requiring cooperation among multiple players whose collective decisions directly affect long-term availability or scarcity.

## Recommendations

### Reporting/metering

Lack of meters and insufficient reporting of usage is an obstacle to developing conservation strategies. Army installations and senior leaders lack adequate information about how installations consume water and about overall supply and demand in regions containing installations. Installation reporting of water consumption is inconsistent and incomplete. The Army Energy and Water Reporting System (AEWRS) is not fully populated with installation-level water consumption and cost data. This was noted in a recent Army Audit Agency report\*.

Installation water conservation plans ideally target high water use activities, however, building level meters are rare and even reimbursable cus-

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\* US Army Audit Agency. 2010. Water Conservation Resources. Audit Report: A-2010-0158-FFE. 18Aug2010.

tomers usage is usually estimated. The Army has set 2016 as the deadline for installing building level water meters. Installation of water meters could be prioritized to support leak detection efforts.

Reporting use and cost at the installation level would give a clearer picture of patterns across the Army. Huntsville maintains a database of natural gas and electric rate structures for Army installations. Data on water rates should also be included in this effort.

### **Technologies**

Per capita water use in the US is higher than many other western countries. Limiting water conservation to the requirements of EO 13514 encourages installations to reach for the low hanging fruit. Technologies that have been considered “business as usual” in countries such as Germany are only recently being implemented in the US. These include high efficiency toilets (HETs) and water-efficient appliances. Readily available water conservation technologies should be required in all Army buildings. This could be accomplished by replacing when needed or by “buying out” an entire technology, for example, replacing every toilet greater than 1.6 gallons per flush. One mechanism for encouraging implementation of desired technologies is to limit purchase/stocking to these items.

The Army should establish a set of technology-based requirements, evaluated using a systems approach. Water efficient technologies should only be specified Army-wide after they have been thoroughly evaluated for systems-wide implications. Modifying one element in the water system in isolation—water end use devices—can cause unforeseen problems in other parts of the system. Ideally, the Army should place itself in the “early adopters” category shown on the Rogers Innovation Diffusion Curve, to assure that technologies are fully developed and understood before implementation (Figure 91). Problems related to reduction of potable water flow include dry drains, incorrect chemical dosing for drinking water, water supply pumps operating outside of optimum conditions, potential for standing water in pipes resulting in flushing and/or additional chemicals, and problems with sewage treatment plant operation due to insufficient water.

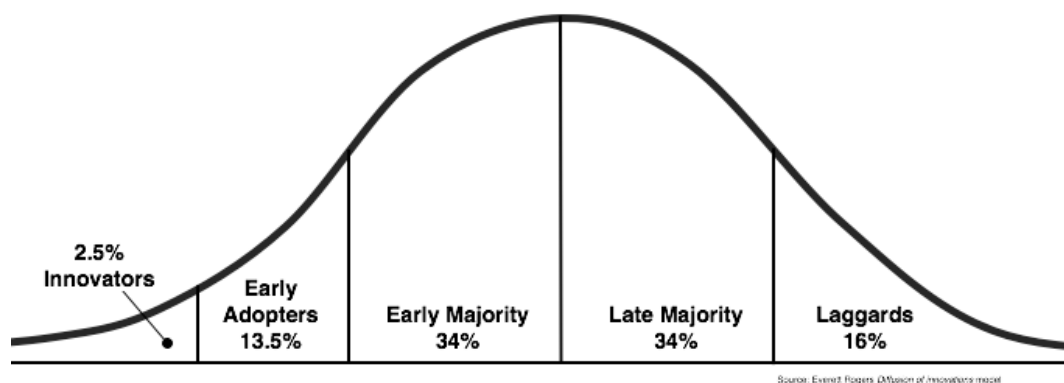


Figure 91. Roger's innovation diffusion curve.

### Distribution systems

In general, the condition of water distribution systems on Army installations is similar to that of the US at large, where a 15 percent leakage rate is the target. Not only are leaks the source of significant water loss but, leaking water also embodies lost energy. Energy inputs occur at water supply and conveyance, water treatment, water distribution, end use, and waste water treatment.

The Army should establish a water loss program that addresses leak detection and repair (this could be independently validated if the AEWRS\* system were used to hold data). The lack of an aggressive leak detection program coupled with a still-to-be installed water metering program causes the Army to waste a currently unknown amount of potable water. Neither the lost water nor energy are accounted for in Army water conservation targets. Thus, these targets are skewed downward without incorporating these data.

### Privatization implications

The Army should address water use/conservation/efficiency in all contracts. One large target is contracts for operation and maintenance of utility systems. Standard contracting language should be developed that requires implementation of measures that will safeguard water, for example, requiring routine leak detection surveys. Other contracting opportunities include the Residential Contracting Initiative (RCI) program for Army family housing. Although the contract operator is responsible for operation and maintenance of utilities, the installation is responsible for achiev-

\* Army Energy and Water Reporting System (AEWRS)

ing water reduction targets and ensuring sustainable water supplies. RCI contracts should include water efficiency requirements and should report their progress in support of attaining water use targets. Another contracting target is reimbursable water customers. These customers, including Non-Appropriated Fund and Army and Air Force Exchange Service\*, are billed for their water use. Building-level meters are rare and these billings are usually based on estimates. Installations should be encouraged to install meters and/or sub-meters (these are optional†) and to monitor use of these customers in support of water reduction targets.

Other targets include family housing contracts that are part of the Residential Construction Initiative (RCI). RCI contractors in the US are billed for their water use when the installation purchases water from an off-site utility company. If the installation is self-supplied, and reported water cost reflects only the cost to treat and pump, the RCI contractor is normally not billed (Murrell 2011).

### **Water rights**

Historic water rights are limiting factors for some installations. Issues related to water rights are coming to a head in many regions. Compacts developed during times of relative water abundance do not provide adequate resources for growing regional needs. Army installations are entitled to water under the Federal reserved water rights doctrine. The doctrine holds that when the US sets aside or reserves public land for uses such as Indian reservations, military reservations, national parks, forests, or monuments, it also implicitly reserves sufficient water to satisfy the purpose for which the reservation was created‡. In terms of Army guidance on water rights, DA memorandum was issued in 1995 (in response to Army Science Board recommendations) to “set forth instructions on how water rights information should be documented and protected at Army installations.”§

The Army should review all policies that relate to installations’ rights to water to determine if it needs to be updated or modified. Each installation should be aware of their right to water and the factors that may affect those rights.

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\* One example of a high water use reimbursable customer is a water bottling facility in Vicenza, Italy.

† Department of the Army. AR 420-41 Acquisition and Sales of Utilities Services. 15Sep1990.

‡ Federal reserved water rights doctrine

§ Department of the Army. 1995. Policy Guidance on Water Rights at Army Installations in the United States. 24Nov1995.

### **Take a holistic approach to Net Zero Water and Energy**

Water resources are sometimes the victim of efficiencies in other resource areas. One of the strongest ties is between energy and water. All energy-related projects should be reviewed to evaluate their effect on water consumption. This needs to include not only installation energy projects, but all renewable projects in the region, including Federal renewable energy projects.

### **Funding water projects**

Although water prices are rising in many regions, the cost does not reflect its scarcity. It remains challenging to obtain a competitive return on investment for many water efficiency technologies. Economic considerations should not be an obstacle to implementing efficiency measures. One option is to establish different Return on Investment/Simple Payback thresholds for water projects than for energy projects. Another is to set aside funding specifically designated for water projects. This has been done historically for energy projects. The Army should consider using funding mechanisms such as the Enhanced Use Lease (EUL) and ESPC programs. It should also consider new water focused contracting mechanisms similar to EULs and ESPC.

### **Regional planning**

Regional assessments for each installation are necessary to both inform and to help prioritize installations for technical solutions. The Army should evaluate all installations for regional water sustainability and partner with regional stakeholders in planning for a secure water future. It is important to note that Army installations are just one, albeit a significant, user of water resources within their regions. However, even large gains in installation water efficiency will not safeguard supplies for continued use if planning for sustainable water resources is not performed regionally. Regional planning should be a high priority for installation water resource planning. This should include participation by the Army Corps of Engineers and the Regional Energy and Environmental Centers (REECs). The Army has four out of ten REECs, which coordinate through their participation in state and regional meetings.

### **Climate change and water**

The results of the studies described in this report point to an array of climate-driven impacts that could affect water security both for the installa-



tions and the regions. Climate change will exacerbate water scarcity in arid regions and affect availability in historically wet regions. The Army should take a proactive approach in planning for sustainable water supplies, particularly for installations that will experience the greatest climate-driven impacts.

### **Command emphasis**

Large reductions in water use will require taking a holistic approach that includes policy, technology, education, partnering with others, and strong command emphasis. The most successful installation water conservation programs share the characteristic of fostering a conservation ethic through outreach and education. Education should be incorporated into every aspect of water management including new technology infusion.

Integrated water management toward achieving “net zero water” can help meet Army water reduction goals with additional benefits of conserving highly treated drinking water, providing a locally-controlled water supply, decreasing diversion of water from sensitive ecosystems, decreasing wastewater discharges, and reducing and preventing pollution. Additional benefits include relieving stress on water infrastructure by reducing water volumes; regulatory mandates and incentives, such as water rate and tax subsidies; and shifting expectations toward sustainability. Army installations located in water-stressed regions compete with local communities for resources therefore best practices in water use also benefit the Army by fostering good community relations.

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## Acronyms and Abbreviations

AAP	Army Ammunition Plant
ACF	Apalachicola-Chattahoochee-Flint (river system)
ACT	Alabama-Coosa-Tallapoosa (watershed)
AEPI	Army Environmental Policy Institute
AF	Acre foot
AFRC	Air Force Reserve Command
ANSI	American National Standards Institute
ASIP	Army Stationing and Installation Plan
ASP	ammunition supply point
AWWA	American Water Works Association
BCWCID	Bell County Water Improvement District
BGRWPG	Brazos G Regional Water Planning Group
BLCC	Building Life Cycle Cost
BLORA	Belton Lake Outdoor Recreation Area
BMP	best management practice
BRAC	Base Realignment and Closure
BUMP	Beneficial use monitoring program
CDEC	California Data Exchange Center
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CERL	Construction Engineering Research Laboratory
CNRA	California Natural Resource Agency
CPSWSF	Central Puget Sound Water Suppliers' Forum
CSA	combined statistical area
CSU	Colorado Springs Utilities
CVWF	Central Vehicle Wash Facility
CWW	Columbus Water Works
DA	Department of the Army
DC	District of Columbia
DEP	(Florida) Department of Environmental Protection
DNR	Department of Natural Resources
DOE	US Department of Energy
DPW	Directorate of Public Works
DWR	Department of Water Resources
DWS	Department of Water Services?
EIS	Environmental Impact Statement
EISA	US Energy Independence and Security Act of 2007
ERDC	Engineer Research and Development Center
ES	Electrical System
ET	evapotranspiration

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FEIS	Final Environmental Impact Statement
FHWMP	Fort Hood Water Master Plan
FOB	forward operating base
GAEPD	Georgia Environmental Protection Department
GIS	geographic information system
HUC	hydrologic unit code
ID	identification
IDM	Installation Demand Model
IMCOM	Installation Management Command
IPCC	Intergovernmental Panel on Climate Change
IPP	Initially Prepared Plan
JBLM	Joint Base Lewis-McChord
KGD	thousand gallons per day
MAG	Managed Available Groundwater
MCAAP	McAlester AAP
MG	Million gallons
MGD	million gallons per day
MGY	million gallons per year
MP	Mission Profile
MRLC	Multi-Resolution Land Characteristics Consortium
MSA	Metropolitan Statistical Area
MTAS	Municipal Technical Advisory Services
MWA	Mojave Water Agency
NEPA	National Environmental Policy Act
NHLD	National Historic Landmark District
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NRW	non-revenue water
NSN	National Supply Number
NWCCOG	Northwest Colorado Council of Governments
NWS	National Weather Service
NYSC	New York State Climate Office
OKCS	Oklahoma Climatological Survey
OLS	Operation Lifeline Sudan
OMB	Office of Management and Budget
ORCS	Oregon Climatological Survey
OWRB	Oklahoma Water Resources Board
PAD	Program on Applied Demographics
PIPC	Palisades Interstate Park Commission
RCI	Residential Communities Initiative
REMI	Regional Economic Models, Inc.
ROTC	Reserve Officers Training Corps
RPI	Raptor Population Index

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RRCA	Republican River Compact Association
RWPG	Regional Water Planning Group
SAIC	Science Applications International Corporation
SAR	Species at Risk
SDS	Southern Delivery System
TCEQ	Texas Commission on Environmental Quality
TNT	trinitrotoluene
TPL	Trust for Public Land
TVA	Tennessee Valley Authority
TWDB	Texas Water Development Board
TWM	total water management
UAW	Unaccounted for Water
BOR	Bureau of Reclamation
UGA	University of Georgia
UIUC	University of Illinois at Urbana-Champaign
URL	Universal Resource Locator
US	United States
USA	United States of America
USACE	US Army Corps of Engineers
USBR	US Bureau of Reclamation
USDA	US Department of Agriculture
USFH	Universal Services, Fort Hood
USGCRP	US Global Change Research Program
USGRP	US Global Change Research Program
USGS	US Geological Survey
USMA	US Military Academy
WCID	Water Control and Improvement District
WRI	World Resources Institute
WSTB	Water Science and Technology Board

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14. ABSTRACT A key concern for the US Army is the vulnerability of military installations to critical resource issues. Water issues of concern, including adequate supply, increased cost of production per unit volume, quality, habitat degradation and salinity issues, already impact military installations and military operations in many locations within the nation and across the globe. There is a need to assess vulnerability of regions and installations to water supply and to develop strategies to ameliorate any adverse effects on military sustainment. These analyses —completed on a watershed level and projected over a 30 year time frame— include estimates of both installation and regional water demand. Assessments were completed for ten Army bases across the United States. Results depict a range of installation water sustainability conditions that reflect the larger picture of water sustainability across the United States and around the world. The Army is applying the results of these studies to develop policies that will support sustainable long-term water supplies.					
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